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Proceedings of the Symposium on the

Ecology, Management, and Utilization of California Oaks

June 26-28, 1979, Claremont, California

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Proceedings of the Symposium on the

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Timothy R. Plumb
Technical Coordinator

CONTENTS

Opening Remarks 1
Robert Z. Callaham

Ecological Relationships

Neogene History of the California Oaks 3
Jack Wolfe
History of Cultural Influences on the Distribution and Reproduction of Oaks in California 7
Randall S. Rossi
Taxonomy of California Oaks 19
John M. Tucker
Natural Hybridization Between Two Evergreen Black Oaks in the North Central Coast Ranges of California 30
Michael C. Vasey
Tanoak (*Lithocarpus densiflorus*) Leaf Surface Characteristics 36
M.G. King and S.R. Radosevitch
Adaptations of Mediterranean-Climate Oaks to Environmental Stress 43
Philip W. Rundel
Wildfire and the Geographic Relationships Between Canyon Live Oak, Coulter Pine, and Bigcone Douglas-fir Forests 55
Richard A. Minnich
The Fire Resistance of Engelmann and Coast Live Oak Seedlings 62
Gerald E. Snow
Inventory and Distribution Records of Oaks in California 67
Timothy E. Paysen
Quercus sadleriana, R. Br. Campst., Its Distribution, Ecology, and Relationships to Other Oaks 75
Gilbert J. Muth
Change in Vegetative Cover of Oak Stands in Southern San Diego County: 1928-1970 81
Carla R. Scheidlinger and Paul H. Zedler
Canyon Live Oak Vegetation in the Sierra Nevada 86
Rodney G. Myatt
Inventory and Quantification of Central Coast Hardwood Resources in California 92
Norman H. Pillsbury
Oaks in California's Commercial Forests—Volume, Stand Structure, and Defect Characteristics 101
Charles L. Bolsinger

Silviculture and Management

Preliminary Recommendations for Managing California Black Oak in the Sierra Nevada 107
John Tappeiner and Philip M. McDonald
An Approach to Managing California Black Oak and Hardwoods on a Deer Winter Range in Central California 112
Donald Potter and Barbara Johnston
Oak Management Harvest A: An Experimental Management and Utilization Project on Southern California Private Ownership 117
James E. Asher
Growth of Thinned and Unthinned Hardwood Stands in the Northern Sierra Nevada . . . Preliminary Findings 119
Philip M. McDonald
Radial Growth of California Black Oak in the San Bernardino Mountains 128
Barbara Gemmill
Prescribed Burning in California Oak Management 136
Lisle R. Green
Nursery Propagation of California Oaks 143
Suzanne Schettler and Michael Smith
Nutrient-Microbial Considerations in Oak Management 149
Paul H. Dunn

Oaks and the California Landscape **161**
R. Burton Litton Jr.
Measures That Can Help Offset the Detrimental Effects That Urban Development Has on Oak Trees **167**
Paul A. Rogers
Aspects of Water Relations in Coast Live Oaks and Valley Oaks Subjected to Root Damage from Land Development Operations **171**
Stephen W. Roberts and Robin L. Smith
Oak Tree Banks and Relocation **176**
Richard D. Cross
Characteristics of Root Systems: California Oaks .. **178**
W.D. Thomas
California Oaks and Outdoor Recreation **180**
Sam S. Alfano

Damage Factors

Insects Feeding on California Oak Trees **184**
Leland R. Brown
Diseases of Oaks in California **195**
Robert D. Raabe
Response of Oaks to Fire **202**
Timothy R. Plumb
Sprouting in Fire-Damaged Valley Oaks, Chews Ridge, California **216**
James R. Griffin
Effect of Chronic Oxidant Air Pollution Exposure on California Black Oak in the San Bernardino Mountains **220**
Paul R. Miller, Gail J. Longbotham, Robert E. Van Doren, and Maureen A. Thomas
Sea-Salt Aerosol Damage to *Quercus agrifolia* and *Quercus lobata* in the Santa Ynez Valley, California **230**
Gary L. Ogden
Tolerance of Oaks to Flooding **238**
Richard W. Harris, Andrew T. Leiser, and Robert E. Fissell
Animal Damage to Valley Oak Acorns and Seedlings, Carmel Valley, California **242**
James R. Griffin

Products

Birds of California Oak Habitats—Management Implications **246**
Jared Verner
Acorn Storage by Acorn Woodpeckers in an Oak Woodland: An Energetics Analysis **265**
Walter D. Koenig
Annual Oak Mast Yields from Visual Estimates ... **270**
Walter C. Graves
Mammals of California Oak Habitats—Management Implications **275**
Reginald A. Barrett
Ecological Relationships Between Southern Mule Deer and California Black Oak **292**
R. Terry Bowyer and Vernon C. Bleich
Trends in Oak Utilization—Fuelwood, Mast Production, Animal Use **297**
John W. Menke and Michael E. Fry
Livestock Utilization of California's Oak Woodlands **306**
D.A. Duncan and W.J. Clawson
Effect of Blue Oak on Rangeland Forage Production in Central California **314**
V.L. Holland
Effect of Blue Oak on Nutritional Quality of Rangeland Forage in Central California **319**
V.L. Holland and Jimmy Morton
Effect of Blue Oak Removal on Herbaceous Forage Production in the North Sierra Foothills **323**
Burgess L. Kay and O.A. Leonard
Oak Trees and Livestock—Management Options .. **329**
Alfred H. Murphy
Energy Yield Potentials of California Oaks and Other Wood Biomass **333**
Al Groncki
Economics of Utilizing Oak for Energy **345**
Raymond Stine
Observations on Wildlife Abundance in Several California Black Oak Habitats in Northern California **354**
Steven J. Kerns
Acorns—Food for Modern Man **360**
Jeanine A. Derby
Wood Products from California Oaks, Cal Oak Lumber Company Style **362**
Guy Hall

PREFACE

In June 1979, more than 200 people met on the campus of Scripps College in Claremont to share information about our native oaks, one of California's most important natural resources. Historical records show that the beauty and value of the arborescent oaks were readily apparent to the early settlers, but during the last 200 years, probably more effort has been spent to remove and kill oaks than to grow and manage them. Efforts by concerned individuals and public resource organizations to manage oaks have generally been ineffective.

Because of the "poor" stem form and the relatively slow growth of most oak trees, professional foresters have generally concentrated their efforts on managing other trees, mainly conifers. Recently, however, broad-scale interest in oaks has developed. The public has become aware of the limitations of our natural resources. The potential of the oak woodlands in meeting energy shortages and wildlife needs, as well as the great immediate value of these woodlands to recreation, are now being recognized. This recognition, and the intense concern now felt about the urbanization of California's woodlands, have contributed to the success of the symposium.

The symposium was sponsored by Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, and the Society of American Foresters. The background for the symposium and its general tenor was set in the opening address by Dr. Robert Z. Callaham, Director of Pacific Southwest Station, who emphasized that the symposium was a joint effort by scientists, land managers, and practitioners representing many different points of view.

Grateful recognition is due the members of the Coordinating Committee, who provided technical support and encouragement:

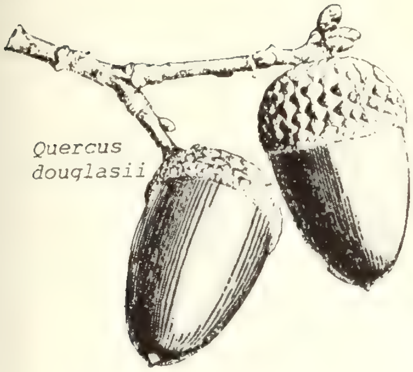
- Leland R. Brown, University of California, Riverside
- Reginald Barrett, University of California, Berkeley
- James R. Griffin, Hastings Natural History Reservation, University of California, Carmel Valley
- Philip M. McDonald, Pacific Southwest Station, Redding
- Norman H. Pillsbury, California Polytechnic State University, San Luis Obispo
- Jared Verner, Pacific Southwest Station, Fresno
- Herbert Hahn, Pacific Southwest Region (R-5), Forest Service, representing the Society of American Foresters.

The chairmen of the four sections of the meeting contributed greatly to the success of the symposium, and their work is sincerely appreciated:

- Ecological Relationships, James R. Griffin
- Silviculture and Management, Philip M. McDonald
- Damage Factors, Leland R. Brown
- Products, Jared Verner

We also thank the many individuals who took care of the multitude of jobs to be done, in particular, DiAnne Broussard, Pacific Southwest Station, Riverside, who served as symposium coordinating assistant. The Chaparral Research and Development Program and the Chaparral Research Work Unit, both of Pacific Southwest Station, Riverside, supported the symposium from its inception.

Timothy R. Plumb
Forest Service, U.S. Department of
Agriculture
Chairman, Coordinating Committee



Opening Remarks[1]

Robert Z. Callaham[2]

I am particularly happy to be here to open this meeting because I know it is needed. Expressions of need for information about oaks in California have been numerous and frequent in recent years. Responding to this need, the Forest Service, specifically our Chaparral Research and Development Program, has organized this Symposium dealing with oaks in California.

You are about to participate in the first meeting ever designed to collect all facets of information about oaks and related species in California. This Symposium is going to make available a great deal of information, much of it heretofore unpublished. People seem to know more about oaks than they have ever bothered to publish. In some disciplines, such as taxonomy and entomology, there is quite a bit of information--very specific and technical. In some other disciplines, such as silviculture and soils, we lack information but hope this Symposium will provide the occasion to pull together what is known.

One primary purpose of this meeting is to identify the information gaps. Some people talk about the state-of-the-art, but I have come to reject that phrase. I have learned to distinguish between the state-of-science and the state-of-practice. These are two important and different subjects. Scientists want to know about frontiers of knowledge and the gaps for further exploration. Practitioners have very little interest in the state-of-science; they are only interested in what is known that can be put into practice today, at what costs, and with what benefits. This meeting strives to describe both the state-of-science and state-of-practice relating to oaks in California.

Although one of California's largest natural resources, oaks are almost unmanaged. Utilization is low, nonexistent, and even designed to reduce the oak resources in many areas. Most foresters either ignore oaks or consider them as weeds. For many years, oaks have been looked upon as a detriment to range management. Currently, where urbanization is invading the oak-woodlands, the oaks are mixed blessings. Some people look upon them as a nuisance impeding progress; and others value them very highly for their individual beauty, for the shade they cast, and for other environmental benefits.

Tremendous interest in oak has developed in the past few years. Some of this interest is undoubtedly generated by the rapid loss of native oaks in urban-range environments. The recent emphasis on renewable energy resources has rekindled interest in the use of oak wood, particularly to replace fossil fuels. There is growing recognition by more than the wildlife professionals that oaks are tremendously important to wildlife habitat. Most of us have at least a subconscious, latent affection for stately oaks and recognize their environmental and social values.

Oaks obviously have more value than just being nice to have around. Traditional uses of oaks for lumber or other wood products (excluding fuel) have been extremely limited in California. This limitation is due partially to poor tree form, problems is seasoning lumber, and high levels of defect found in our native trees. But some innovative milling techniques have overcome many of these past problems. Utilization of native oaks for lumber is increasing. Modern laminating techniques and seasoning procedures have made it practical to use small and otherwise unusable wood resources.

But oaks have many values other than being just a source of wood products. Their value for watershed protection, wildlife habitat, recreational enjoyment, and general esthetics far exceed their potential value as wood products. With these other values in mind, crooked, branchy trees with a high incidence of defect may not be valueless. But what are their values? One accomplishment I would like to have

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[1] Presented at the Symposium on the Ecology Management and Utilization of California Oaks, June 26-28, 1979, Claremont, California.

[2] Director, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, California.

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from this meeting is an expression of how we might quantify the nonwood values of oaks.

Fire, the constant threat to all forest trees in California, may cause extensive damage and reduced lumber values, but it may not seriously affect the nonlumber values of oaks. In almost every location where conditions permit tree growth, one or more species of oak can be found. They are a component of the major vegetation types. For example, here in Southern California, they grow in the valleys below the chaparral, in the chaparral itself, as fingers in the riparian draws and drainages that dissect the chaparral, and then on up into the conifer forest above.

Unfortunately, we do not have an accurate estimate of California's oak resource. Oaks are estimated to grow on about 15 to 20 million acres in California. That acreage forms 15 to 20 percent of the entire state. This estimate includes only about 5 million acres of commercial forest land. Estimates of the volume of oak resource are traditionally based only on trees that grow on these commercial forest lands. So we really have no idea of the current volume and value of oak in California. Certainly, the current growth of oaks greatly exceeds their utilization for any products or values.

The Forest Service, other organizations, and individuals have attempted to manage oaks. These efforts have met with little or no success. Obviously, the technology for management is lacking.

The Chaparral R&D Program, launched by the Forest Service in Southern California in November 1977, sent out a questionnaire asking about interest in oak management. Responses evidenced a very high level of interest. Eighty percent of the respondees indicated a mild to intense interest in oaks. This response caused us to bring together 70 people a year ago to plan for this Symposium. Consequently, this meeting is the result of a joint effort by many different institutions and by people having diverse interests, organizational affiliations, and professional backgrounds.

Here we are at the fruition of our planning. More than 50 papers provide a cross section of many interests and viewpoints about oaks. Papers range from highly technical to very practical. There should be something of interest for everyone in the audience. We want your active participation. You are a small enough group that your inquiry and dialogue as a committee-of-the-whole will be meaningful and rather easy to manage. Please join in, ask questions, and seek out people having interests related to yours. Whoever knows about oaks should be in this room. You should be able to find the people that have some information on almost any question. I know that you will benefit from this meeting, and I wish you success. Thank you for coming.

Ecological Relationships

Quercus wislizenii

Neogene History of the California Oaks[1]

Jack A. Wolfe[2]

Abstract: The Neogene oaks of California and adjacent states represent groups that have survived in California today. The Agrifoliae, Lobatae, and Quercus chrysolepis have a history largely in the summer-wet Miocene forests of the Pacific Northwest. The white scrub oaks and Q. tomentella apparently originated in California or in areas to the southwest. The associations and geographic ranges of the California oaks were probably greatly altered during the climatic fluctuations of the Pleistocene.

The fossil record has only a limited contribution at this time relative to the phylogenetic relationships within Quercus. This is partially because of the difficulty in working with foliage in a polymorphic genus, concomitant with the problems of foliar convergence and parallelism such as discussed by Tucker (1974). Even more significantly, fossil plant assemblages older than 22 to 23 million years--that is, pre-Miocene and pre-Neogene--are unknown in the lowland areas of southwestern North America, except for Paleocene and older assemblages, which probably predate the evolution of oaks.

Foliage of species displaying characters of Lepidobalanus, Erythrobalanus, and Protobalanus occurs in the Florissant flora of Colorado (MacGinitie, 1953), which is of late Eocene age. The relationships of any of the Florissant oaks to any extant species or species groups are, in my opinion, highly conjectural. Not until the Miocene can many fossils be confidently relegated to particular species groups of extant oaks.

A review of the Neogene (Miocene and Pliocene) oaks of western North America indicates that almost all of the species groups extant in California had evolved by sometime in the Miocene. In the Pacific Northwest during the early to middle Miocene, the flora included at least three species of Agrifoliae; one of these represents the ancestor of Quercus kelloggii. During the Neogene this lineage undergoes progressive foliar evolutionary trends such as 1) an increase in number of lobes, 2) an increase in the degree of dissection of the lamina, and 3) an increase in the frequency of secondary teeth on the lobes. This lineage includes leaves variously referred to Q. pseudolyrata Lesq., Q. merriami Knowlt., and Q. deflexiloba H. v. Sm. A closely related species is Q. cognata Knowlt. and its undescribed descendant species; this lineage maintained the presumably primitive shallow and few-lobed conditions and became extinct by the end of the Miocene. An undescribed oak from the Latah flora of Washington is allied to Q. agrifolia and Q. wislizenii, although the fossil may not be directly ancestral to either species. The next youngest record of this type is Q. cedrusensis Wolfe from the late Miocene of Nevada (Wolfe, 1964).

Also represented in the early to middle Miocene of the Pacific Northwest is a species of Protobalanus closely allied, and probably ancestral, to Quercus chrysolepis Liebm. By the middle to late Miocene, foliage apparently indistinguishable from Q. chrysolepis is of wide occurrence in the Pacific Northwest, as well as in more southern areas (Wolfe, 1964, 1969).

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[1] Submitted to the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Geologist, Geological Survey, U.S. Department of Interior, 345 Middlefield Road, Menlo Park, Calif.

Lobed species of Lepidobalanus occur in the Neogene of the Pacific Northwest. The earliest of these--Q. columbiana Chan.--is typically simple-lobed, although some specimens possess rare teeth on the lobes. Some of the specimens have decidedly rounded lobes, but some have very sharp--almost spinose--lobes, indicating a possible relationship to the bristle-tipped Asian species of Lepidobalanus. Several specimens of the early and middle Miocene Alaskan Q. furuhjelmi Heer are definitely bristle-tipped (Wolfe and Tanai, in press), and thus the Pacific Northwest species could conceivably include some genetic influence from Q. furuhjelmi. In any case, one descendant of this probable plexus--Q. winstanleyi Chan.--represents an extinct and simple-lobed lineage. By the late part of the middle Miocene, a second lineage is consistently compound-lobed and is clearly leading to Q. garryana and Q. lobata.

Yet another group is represented in the Neogene of the Pacific Northwest. The relationships of the species known as Quercus simulata Knowlt. have been much discussed. Some workers (e.g., Chaney and Axelrod, 1959) have favored a relationship to certain Asian species that are segregated by many systematists into the genus Cyclobalanopsis. A recent chemical analysis of leaves of Q. simulata (invalidly referred to Q. consimilis) by Niklas and Gianassi (1978), however, indicates that the fossil is closely related to Asian oaks such as Q. acutissima and Q. chenii but not to any of the cyclobalanopsid oaks. Unfortunately, Niklas and Gianassi did not include in their analysis of extant species the west American Q. sadleriana; this species has several critical morphological similarities in foliage to Q. simulata and Q. acutissima. It seems most probable that Q. simulata represents the same species group as does the extant Q. sadleriana. It would, however, be highly conjectural at this time to derive Q. sadleriana directly from Q. simulata. Also included in this species group is Q. bockei Dorf from the Pliocene of northern California.

The species known as Quercus dayana Knowlt. has been likened to the eastern American Q. virginiana (Chaney and Axelrod, 1959); in marginal and ultimate venation, however, the fossils represent Castanopsis. A second species known as Q. eoprinus H. v. Sm. has, as the epithet indicates, been compared to another eastern American oak; in several critical characters, the fossils can be demonstrated to represent Fagus. Thus, all the Neogene oaks now known in the Pacific Northwest appear to represent species groups that are still extant in western United States.

The known Neogene floras from Nevada appear to represent vegetation that grew at a considerable altitude and that is floristically closely allied to the Neogene floras of the Pacific Northwest (Wolfe, 1969). All the oaks now known represent the Agrifoliae, Quercus simulata, or Protobalanus allied to Q. chrysolepis. The one specimen attributed to the Lobatae (Axelrod, 1958) is a fragmentary lobe of the Acer macrophyllum type.

In California, the early to middle Miocene flora is known from only two assemblages: the undescribed Valley Springs flora from the early Miocene in the western foothills of the central Sierra Nevada and the Tehachapi flora from the middle Miocene of the Mojave desert (Axelrod, 1939). The oaks in the latter flora are in great need of work with modern techniques of foliar analysis. Members of Protobalanus are probably present in the Tehachapi, but whether the scrub oak type of Lepidobalanus is also present remains to be demonstrated. The only oak in the Valley Springs assemblage is closely related to Quercus tomentella of Protobalanus.

During the late Miocene--5 to 13 million years ago--relatives of most of the extant California oaks were represented in California. Some of these, however, first appear in the latest Miocene, that is, younger than 10 million years. For example, the group now represented by the blue oak, Quercus douglassii, is not known until the latest Miocene in California (Condit, 1944), and possibly all the Dumosae also appear at about this time. Considering the general excellence of the Neogene record in the Pacific Northwest and Nevada, I think it reasonable to conclude that oaks such as the white scrub oaks were either present in California lowland areas in the early Neogene or entered the state from the southwest.

One point that the fossil record clearly indicates is that there has been little interchange of oaks between North America and Eurasia. Only in Lepidobalanus can some interchange be documented, and even this was very limited. No oaks referable to Erythrobalanus or to Protobalanus are known in Eurasia or even at high latitudes in North America. The most northern occurrence of Erythrobalanus is in northern Washington during the middle Miocene. For Protobalanus the most northern occurrence is at latitude 54° in central British Columbia, also during the middle Miocene.

What is perhaps of more pertinence to this symposium is to learn from the fossil record the general climatic-ecologic background of the California oaks. That is, have certain lineages been confined to a particular climatic regime for millions of years, which would indicate little adaptive ability? Or, have some lineages shown considerable tolerance of various climatic regimes?

If paleobotanists relied strictly on present climatic tolerances of extant relatives of fossil species to determine the climates under which various assemblages lived, I would certainly run the risk of circuitous reasoning. However, paleobotanists also use data based on the physiognomy of fossil assemblages; for example, types of leaf margins, leaf sizes, proportions of conifers, broadleaved deciduous, and broadleaved evergreen plants, etc. Such physiognomic analyses are independent of the taxonomic composition of a fossil assemblage and thus allow an evaluation of the various climates under which various lineages and species groups have lived (Wolfe, 1971).

In regard to the Agrifoliae, the fossil record strongly indicates that the evolution of the group was centered in the Pacific Northwest. During most of the Miocene, this region was characterized by summer rainfall; by the late Miocene, however, the amount of summer precipitation was declining. Summer temperatures were generally higher than now, and, during the early and middle Miocene, the mean of the warmest month was certainly 20 to 24°C. The known records of the Agrifoliae during the early and middle Miocene are in vegetation that was a diverse broadleaved forest. Although the Quercus kelloggii lineage also occurred in lowland broadleaved forest during the late Miocene, many occurrences are also in upland Mixed Coniferous forest. In such forest, warm month means are consistently less than 20°C. By the late Miocene, therefore, the Q. kelloggii lineage had adapted to approximately its present temperature range, but the lineage has shown a progressive adaptation to drier summer regimes.

Quercus agrifolia and Q. wislizenii have somewhat problematic records. Related fossils occurred in summer-wet assemblages in the Pacific Northwest in the middle Miocene and in drier but probably still summer-wet assemblages in Nevada during the late Miocene. Both lineages became abundant by the latest Miocene in California under even drier conditions.

The climatic history of the Lobatae parallels that of the Q. kelloggii lineage: adapting from summer-wet to summer-dry climates during the Neogene. It may be significant that the oldest occurrence of the Q. douglassii lineage is in a mesic summer-wet assemblage in the northern Sierran foothills during the latest Miocene. The blue oak may well be a late Neogene derivative in California of the Lobatae.

The Quercus chrysolepis lineage appears since the middle Miocene to have been primarily a member of Mixed Coniferous forest--that is, to areas of moderate summer temperatures. This lineage appears to have been more common in late Miocene assemblages that, although existing under summer rain, were somewhat dry. Thus the lineage appears to have occupied areas that were climatically similar to areas in the present range of Q. chrysolepis.

In regard to the lepidobalanid scrub oaks and tree species such as Quercus engelmannii and the protobalanid Q. tomentella, the oldest occurrences of these are in subhumid assemblages. The presumption is that such lineages have a long history in dry environments. However, the evolutionary and ecologic history of these oaks will await future paleobotanical work.

One point that must be emphasized is that the geographic ranges of the California oaks were drastically altered during the Pleistocene, and such alterations occurred several times. During an early Pleistocene glacial, for example, the lowland vegetation near San Jacinto included both Quercus chrysolepis and Q. wislizenii (Axelrod, 1966). During the later Pleistocene Illinoisan glacial, the lowland area around Clear Lake in the North Coast Ranges was occupied by a Mixed Coniferous forest that contained Q. chrysolepis; this area is now a woodland of blue, California white, and interior live oaks. During the Yarmouthian interglacial, the blue and interior live oaks occurred abundantly at Clear Lake, but no California white oak has been found. Not only have the geographic ranges of the California oaks been repeatedly altered during the Pleistocene, the particular oak woodland communities may have undergone significant floristic change.

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History of Cultural Influences on the Distribution and Reproduction of Oaks in California[1]

Randall S. Rossi[2]

Abstract: Prior to the advent of European colonization, the California Indians' impact on oaks was confined to acorn collecting and the occasional use of fire. Since 1769 oaks have been vulnerable to six human activities: stock raising, wood cutting, agriculture, flood control, fire supression, and urbanization. Specific research concerning human impacts on the distribution and reproduction of oaks has been meager. In this survey of cultural influences, grazing activity is identified as the most persistent pressure on oak reproduction. Charcoal production consumed a significant amount of oak until the 1960's; incomplete data suggest that cordwood sales continue to account for much wood cutting. Agricultural clearing, initially for orchards, and later for row and field crops, has greatly reduced the range of some species, e.g. valley oak (Quercus lobata). Extensive clearing of blue oak (Q. douglasii) from foothill range in the late 1950's and 1960's was partially supported by federal payments. Riparian oak in the Sacramento Valley have been disappearing since early American occupance and today only a fraction of the original woodland remains. Because of fire suppression efforts since 1900, the build up of fuels and the invasion of woody plants in oak communities make lethal, high-intensity fires more likely. Finally, urban and suburban land uses continually displace native oaks and condemn remnant stands to slow decline without replacement.

INTRODUCTION

Human activities of the last two hundred years have greatly reduced the range of many California oaks and adversely affected their reproduction. While we are aware of the general course of this demise, the actual losses have been incremental, unchallenged, and unrecorded. Further, we are only beginning to ask: What are the consequences of this impoverishment of the landscape?

This paper surveys the state of our knowledge about human impacts on California's oaks. Historically, oaks have been vulnerable to at least six human activities: stock raising, wood cutting, agriculture, flood control, fire supression, and urbanization. The biggest change of the last two hundred years, of course, is that the foothills and valley floors, once occupied by many species of oaks, are largely covered by the farms, cities, and freeways of twenty-two million people.

Four major oak communities, covering about 10 percent of the state, have been recognized as part of California's original landscape. These are: 1) Northern Oak Woodland of the North Coast Ranges and valleys, (Quercus garryana, Q. kelloggii, Q. chrysolepis, and Q. wislizenii); 2) Foothill Woodland of the alluvial terraces

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979

[2] Ph.D. Candidate, Geography Department, University of California, Berkeley.

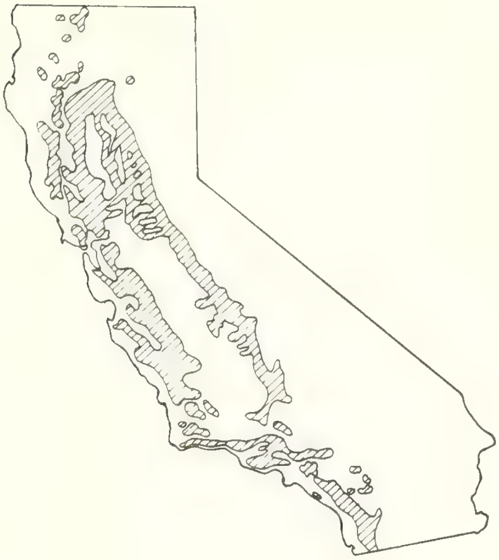

Figure 1 - Areas of Oak Savanna and Woodland in California

and surrounding hills of the Central Valley and Inner Coast Ranges, (Q. douglasii, Q. lobata, Q. chrysolepis, Q. agrifolia, and Q. wislizenii); 3) Southern Oak Woodland of the coastal valleys of Southern California, (Q. agrifolia, and Q. engelmannii); and 4) Riparian Woodlands especially on the Central Valley river margins, where valley oaks (Q. lobata) were locally abundant (Munz and Keck 1963; Griffin 1977).

Each species and certain associations have sustained different kinds of impacts at different times. While some areas are relatively unchanged, in others some species have been eliminated over wide areas, or exist only as remnant stands. And where individual trees or woodland tracts remain there may be a false sense of well-being, since few, if any seedlings are becoming established.

The nature and extent of human impacts on oaks before 1930 is not comparable to that of the last fifty years. Pressures on oaks have increased due to the rapid increase and spread of population, increasing land values, the lengthy periods of fire suppression, the development of practices and machinery for clearing range land, channelizing streams, and building roads and cities. The oaks, which were the single most important plants in the lives of the Indians, are valued by modern man only as amenities in real estate.

Oaks are part of what we define and identify as typically Californian. Attention naturally focuses on the California endemics, Quercus lobata (valley oak) and Q. douglasii (blue oak) which are widely distributed in and around the Central Valley and Coast Ranges. The valley oak, largest of the North American oaks, grows on deep alluvial soils and up onto broad ridge tops. It often forms strikingly beautiful savannas, having a parklike appearance. The blue oak grows on rolling hills and drier sites, singly or in clumps, and is common on thousands of acres throughout the state.

The task of reconstructing how our oak woodlands have changed is a difficult one, and there will always be great gaps in our knowledge. Only a handful of studies have been concerned with landscape changes in the oak woodland (Thompson 1961; Brooks 1967; Vankat 1970; Griffin 1971, 1976; Snow 1972; Dutzi 1979; Rossi 1979). While university and government personnel have advocated and aided in the clearing of thousands of acres of oaks, no state or federal agency has monitored or inventoried the extent or cumulative effects of the activity. Today we find we lack any accurate estimates of even the most recent clearing. Further, with notable exceptions (Griffin 1971, 1976; Snow 1972), the conspicuous lack of oak regeneration, perhaps the most important issue in oak management, has received virtually no study. In strong contrast to the long history of conservation and land stewardship examined by Parsons (1962) in Spain's oak woodlands, California oaks have been disregarded as a natural resource.

ABORIGINAL INFLUENCES

The extensive, almost continuous oak woodlands and savannas of California provided the staple food of the native Indians for centuries. The acorn and the oak were worshipped by these hunter-gatherers (Fages 1937). The extent of their adverse impact on oaks was confined to acorn collecting and the occasional use of fire.

An estimated 500 pounds (230 kg) of acorns were consumed each year (Hoover 1977). In poor seed years it is likely that nearly all of the crop from some species was collected and stored. The preference for acorns of tan oak (Lithocarpus densiflora) and California black oak, (Q. kelloggii) and the accessibility of acorns from valley oak must have created a considerable pressure on these species (Chestnut 1902; Baumhoff 1963). In the Central and Southern Coast Ranges, coast live oak (Q. agrifolia) sustained California's densest Indian population. The effects on reproduction of acorn collecting should not be ignored, but the extent to which it may have altered oak distribution is not known.

The use of fire to clear the ground before acorn harvesting has been noted in Northern California and Yosemite Valley (Baxley 1865; Harrington 1932; Schenck and Gifford) 1952). Fire was used to drive game, aid in collecting food, and make clearings for growing tobacco (Kroeber 1925). Any such fire could kill oak seedlings, but light ground fires would not harm established trees. Captain Belcher observed on the Sacramento River in 1837 that during the dry season the natives burned the annual growth, "and probably by such means destroy many oak plantations which otherwise would flourish" (Belcher 1969, p.48). Hinds, a botanist on Belcher's expedition reported Sacramento Valley natives' practice of lighting their fires at the bases of valley oaks. He continued, "and as they naturally select the largest, it was really a sorrowful sight to behold numbers of the finest trees prematurely and wantonly destroyed" (Hinds 1844, p. 3). From this brief description the death of the trees must be interpreted as accidental, since they represented a perennial food resource.

Regarding the valley oaks, Jepson felt "it is clear that the singular spacing of the trees is a result of the periodic firing of the country — an aboriginal practice of which there is ample historical evidence" (Jepson 1923, p. 167). Lewis (1973) has argued that the California native had an active role in manipulating vegetation with fire. Sampson (1944), Burcham (1957), and Clar (1959) have suggested the influence was more benign. Periodic burning by the California Indians may have thinned oak stands or caused certain areas to remain open, but probably was not a significant factor in altering the overall abundance or distribution of oaks.

EARLY STOCK RAISING

Before European contact, California oaks were principally a food resource, and had evolved in the absence of grazing, agriculture, or commercial uses. However, this changed forever when the Spaniards brought their faith, agriculture, and grazing animals to Alta California in 1769. Cattle and sheep certainly consumed acorns and many seedling oaks in the vicinity of the missions. The grazing tracts, or ranchos, of many missions were in oak studded lands, for example Mission Santa Clara, San Jose, San Antonio, San Miguel, Santa Ines, and San Juan Capistrano. Jepson (1910) observed that the chain of missions corresponded roughly to the range of the coast live oak, and that Spanish land grants encompassed most of the valley oak forests. Local overgrazing, droughts, and the introduction of Mediterranean annual plants contributed to the rapid replacement of the original bunchgrass vegetation (Hendry 1931; Burcham 1957). There is evidence that this change resulted in greater competition for oak seedlings in the thick annual cover (Holland 1976).[3] Further, poisoning and trapping of predators, coupled with the increase in seed-bearing plants, has brought an increase in seed-eating rodents and birds, putting added pressures on the acorn crop (Holland 1976).

When a mission was established, it would customarily receive from other missions gifts of livestock to begin new herds. In 1827, four years after the founding of the last mission, Thomas Coulter reported that collectively they had 210,000 branded and 100,000 unbranded cattle (Coulter 1951).

Grazing continued to be the most widespread pressure on oaks throughout the Rancho era that followed mission secularization in 1833. Most of the land grants and grazing activity were in the Southern and Central Coast Ranges where huge herds roamed the grasslands and the woodlands alike (Cleland 1941). Burcham (1957) in his history of California range land considers the foothill woodland a grazing resource second only to the grasslands. In the woodlands, grazing impacts are highly selective, since cattle seek out the shade, devouring the oak seedlings and acorns. Further, repeated trampling of clay soils makes germination of woody plants more difficult (Wells 1962). The acorn crop suffers doubly because of its palability and the time of its ripening at the end of the dry season when forage is scarce. Bryant (1848) observed in the Central Valley that "during the period of transition from the dry grass to fresh growth, horses, mules, and even horned cattle, mostly subsist and fatten upon these large and oleginous nuts" (p. 351). Jepson (1910)called the acorns of blue oak in the Sierra foothills "one of the ranchman's assets for stock feed" (p. 216.).

Beginning in the late 1700's swine fed on acorns at Mission San Antonio and other missions (Bolton 1926; Engelhardt 1929). During the 19th century hogs were driven to oak groves for mast feeding in the Coast Ranges (Q. agrifolia), Central Valley (Q. lobata), and Sierra foothills (Q. douglasii), and the acorns were also collected and fed to the animals in lieu of grain (Bryant 1848; Sudworth 1908; Jepson 1923; Fages 1937). In the 1920's hogs were still being fattened on acorns in the Santa Lucia Mountains for shipment to San Francisco (Coulter 1926).

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[3] Personal communication, C.B. Hardham, Botanist, Paso Robles, California.

In 1834 the number of cattle held by the missions alone was estimated to be 400,000 (Bolton 1917). As private ranchos replaced the mission holdings, stock raising spread throughout the state. Cattle numbers burgeoned in response to the Gold Rush influx, until an estimated one million roamed the land in 1860 (Burcham 1957). From 1849 on, month-long cattle drives were regularly made from Southern California ranchos to San Francisco. Treks involving herds of several thousand were made through the Central Coast Ranges and San Joaquin Valley in the fall as the acorns ripened (Cleland 1951). The drought of 1862-64 brought cattle numbers plummeting, but the oaks continued to suffer. During the droughts of 1862-64 and 1897-98, small trees and branches from larger ones, especially Q. agrifolia in the South Coast Ranges, were cut to provide browse in the path of starving cattle and sheep (Jepson 1910; Lynch 1935). The recurring droughts, while temporarily reducing the cattle population, actually heightened the immediate grazing pressures, and seedling oaks stood little chance of survival.

In the 1870's and 1880's the livestock industry began recovering with sheep numbers reaching over four million in 1880, and cattle one million again by 1890 (Burcham 1957). During the wheat "bonanza" decades at the end of the 1800's, grazing land was pushed out to the margins of the cropland, and into the oak woodland and foothills (Hutchinson 1946). The poor natural reproduction in California's oak woodlands since that time has been generally attributed to grazing-related influences (Sudworth 1908; Jepson 1910).

WOOD CUTTING

In 1793 on Vancouver's voyage down the California coast,parties were landed near Santa Barbara to secure water and fuel. Menzies reported in his journal wood "was easily procured at no great distance from the beach as there were some large trees of a kind of ever green Oak, which they were suffered to cut down for the purpose" (Menzies 1924).

During the 19th century, oak wood was a primary source of fuel, but it is impossible to know how much was cut for this purpose. It was reported that mission padres in the San Gabriel Valley had instructed the Indians to cut only oak tree limbs for fuel "preserving the trunks with sacred care" (Clar 1957). Oak wood was used for heating and cooking throughout the mission and rancho period. Fuel and timber demands were locally heavy during the mining era. Blue oak and pine were used as fuel and mine timbers in the Mother Lode mines, with forest removal greatest in El Dorado County (Watts 1959). Oak wood was used to fuel the quicksilver (mercury) retorts at New Almaden (Santa Clara Co.) and New Idria (San Benito Co.), as well as at mines in Napa, Lake, and San Luis Obispo Counties (Yale 1904).[4]

Fire wood cutting was incidental to land clearing in some instances, but in others a profitable activity in itself. Sudworth (1908) noted that valley oak from the river banks, and interior live oak (Q. wislizenii) from the Sierra foothills were "highly prized for domestic use" in the Sacramento Valley. In 1914-1916, as part of an orchard development, 20,000 cords of oak (valley oak, blue oak, coast live oak) were cleared from 12,000 acres (4800 ha) on the Salinas River near Atascadero in San Luis Obispo County (Rossi 1979). The wood was shipped by rail to San Francisco and Los Angeles. There are, no doubt, numerous examples such as these from all over the state.

For more than a century oak has been the preferred wood for manufacture of charcoal in California. Bancroft (1890) says that charcoal from oak had been burned in California since the early 1850's. Oak was cut around San Francisco Bay to supply charcoal burners in the 1850's and 1860's (May 1957). In 1855, 11,000 bags of charcoal, the equivalent of 110 tons made from "red", white, and live oak, was consumed in and about San Francisco. In the 1860's powder mills in Santa Cruz and Marin Counties used charcoal as a major constituent of their product. In the 1880's the Clipper Gap Iron Company annually burned 10,000 to 15,000 tons of charcoal in its furnace near Auburn, requiring as much as 30,000 cords of wood each year (May 1956).

In the early 1900's charcoal from oak was made in large quantities throughout the state, especially in Sacramento, Shasta and Sonoma Counties. Between 1905 and 1910 California's annual charcoal production averaged 160,000 sacks from 3200 cords of wood. Sonoma County was the top producer then, with about 100,000 sacks annually, or about 1,000 tons of charcoal per year. In 1914 at Heroult on the Pit River, a site now under Shasta Lake, 50 cords a day of California black oak were distilled to charcoal for the Noble Electric Steel Company (May 1956).

In the decades from 1920 to 1940 there were only a few charcoal plants of substantial size in operation. During the early 1920's a charcoal plant near Templeton in San Luis Obispo County was making charcoal out of coast live oak and valley oak, and one near Ukiah in Mendocino County was using canyon live oak (Q. chrysolepis). In 1939 about 1400 tons were produced, but eight years later only a few small kilns in San Luis Obispo County were operating (May 1956). However, ten years later, following World War II, the increasing popularity of "outdoor living" sustained the operation of over forty charcoal plants once again in the state. A 1955-56 survey found 30 wood charcoal kilns in San Luis Obispo County, seven in the Sierra foothills, and four in Southern California. In that year San Luis Obispo accounted for more than 80 percent of the 4,650 tons produced (May 1957). Questionnaires determined that 99 percent of the wood burned was oak. Coast live oak was the most commonly used in San Luis Obispo County, cut from the Santa Lucia foothills in the Upper Salinas Valley. Oregon white oak (Q. garryana) was used in Sonoma and Yolo Counties; blue oak and to a lesser extent California black oak in the Sierra foothills (May 1957). By 1961 twenty producers in California were making 5,400 tons of charcoal from 10,000 cords of oak; eleven of these were in San Luis Obispo County (USDA 1963). In the last 15 years, production in the state has dwindled as inexpensive imported charcoal has become available from Mexico.

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[4] Rossi, R.S. (1975) The quicksilver mines of the Santa Lucia Mountains in northwestern San Luis Obispo County, California. Unpublished manuscript. 40 p.

Use of California oaks for manufactured products has always been limited. Jepson (1923) thought when the name "Mush Oak" was applied to valley oak it was a contemptuous reference to its failure to meet the requirements of a strong, straight wood. He says that the most valuable oak, canyon live oak, was used for shipbuilding, wheels, axles, plow beams, tool handles, and furniture in the early days of the state (Jepson 1910). Coast live oak and blue oak were utilized to a lesser extent for tools and wagon parts. In the 1870 - 1880's in Mendocino County, the forks of open grown California black oak were used as "naturally assembled" ship keels and ribs (McDonald 1969). Wood from valley oak was used in California shipyards during World War II for keel blocks, and a very limited use has been made of it for wine barrels (Schniewind and Bryan 1959; Dost and Gorvad 1977).

Generally oaks have not been managed for commercial uses in California, and in conifer stands have been considered undesirable forest components. California black oak in particular has been removed from softwood stands on state and national forest land, where experiments have shown trees as large as 24" dbh can be poisoned by herbicides (Otter 1960). However, California black oak remains the most important commercial hardwood species in the state.

Statistics point out that 7.8 million board-feet of hardwoods were cut in 1976, virtually all of it California black oak. At the state's largest hardwood mill, Cal Oak, located at Oroville, the wood is used primarily for pallet stock, with a small volume entering furniture manufacturing in Los Angeles.[5] A smaller amount of white oak, mostly Q. lobata is cut annually, and estimated to be between one and two million board-feet (Dost and Gorvad 1977). Recently riparian oaks (Q. lobata) have been cut and sold for wood chips (McGill 1975). Additionally, each year thousands of cords of oak firewood are sold in metropolitan areas, but the sales reported are only a fraction of the actual volume involved. In 1977 California Department of Forestry reported 18,500 cords of fuelwood cut in the state (California Dept. of Forestry 1977). For the last three quarters of 1977 the State Board of Equalization reported 6,000 cords of oak firewood sold in California (three million board-feet)[6] but this may reflect as little as 10 percent of the total.

AGRICULTURE

Throughout California's history, agriculture has displaced extensive tracts of native oaks, and eventually much of the land has become sprawling suburbs. Agricultural operations have made reproduction virtually impossible even when mature trees have been left in the cropland.

The earliest agricultural clearing affecting oaks was for orchards. Following the early Gold Rush immigration, orchards were planted where blue oak, black oak and interior live oak had been cleared from the Sierra foothills (Hutchinson 1946). Between 1900 and 1920 orchards expanded greatly in the Sierra foothills, and in the 1930's Placer, El Dorado, and Nevada Counties were still among the top four counties in pear acreage (Hutchinson 1946; Watts 1959). Early orchards planted on the broad natural levees of the Sacramento River were at the expense of riparian valley oak groves, especially between Rio Vista and Marysville.

In the Santa Clara Valley, the expansion of orchards in the early 1900's led Broek (1932) to observe: "Once a grassland dotted with evergreen oaks, a large portion of the valley is now covered by a veritable forest of deciduous trees" (p. 137). In the Coast Ranges around Paso Robles, a huge promotional development from 1915 to 1925 converted 8,000 acres (3200 ha) of dense coast live oak woodlands and 6,000 (2400 ha) acres of valley oak and blue oak savanna to almond orchards.[7/] When most of the acreage proved unprofitable due to marginal rainfall, early frosts and increasing competition from irrigated plantings, the trees were removed in favor of dry farming uses. At least from 1910 on it was recognized that oaks are host to the fungus Armillaria mellea, which may subsequently attack the roots of orchard trees (Smith 1909). After 1925 fewer oaks were cleared specifically for orchards.

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[5] Personal communication, Brian Barrette, California Department of Forestry.

[6] Personal communication, J.C. Denny, Chief, Resource Management, The Resource Agency, State of California.

For cropland, however, as Jepson (1910) observed, early settlers knew well that the presence of valley oaks was a "sign of the richest soil". Being flat and accessible, these parklike, often pure stands of valley oak, developed on deep alluvial soils, have continually been under the greatest pressure from agriculture. Land cleared of valley oaks includes huge tracts on the east side of the San Joaquin Valley, where today scattered individual trees on the Kaweah River plain attest to the report of 400 square miles (104,000 ha) of valley oaks there in 1910 (Jepson 1910). Valley oaks have been removed or isolated by agricultural uses in the Sacramento Valley, Livermore Valley, Napa Valley, Santa Clara Valley, parts of the Santa Ynez Valley, and the upper Salinas Valley. Round Valley in Mendocino County and San Antonio Valley in the Santa Lucia Range are examples of a few locations where sizable valley oak savannas remain.

In 1861 William Brewer traveling through northern San Luis Obispo County remarked: "... in these valleys are trees every few rods — great oaks, often of immense size, ten, twelve, eighteen, and more feet in circumference ... In passing over this country, every hill presents a new view of these trees — here a park, there a vista with the blue mountains ahead" (Brewer 1864, p. 93). Today, in this area where I have examined the extent of clearing, over 70 percent of the valley oak parkland has been eliminated to facilitate agriculture. Of the trees that remain, nowhere is there a reproductively viable tract of Q. lobata (Rossi 1979).

Clearing, however, is not the only activity affecting the survival of oak savanna. More important is the widespread lack of reproduction. Even where mature trees remain in the fields, reproduction is precluded by recurring planting and harvest operations, and the practice of grazing animals on the crop stubble, where they eat both the acorns and any seedling trees. Characterizing the plight of valley oak, Griffin (1973) observed: "... the scene is now one of tired relics towering over an intensively cultivated system" (p. 6). Very often the only areas where oaks become established is in waste places, abandoned fields, and along roadsides, between the asphalt and the fences. Ironically, one place in San Luis Obispo County where thickets of valley oak saplings have become established is on the freeway borders and median.

STOCK RAISING

Over a large area, particularly in the foothill woodland, grazing activities have caused the same impacts on oak reproduction. The results of predator control and overgrazing included explosive ground squirrel numbers, which in at least one instance, at Fort Hunter Liggett, received national attention.[8/]

Oak reproduction also has been found absent in areas protected from grazing (White 1966). Mice, wild pigs, and especially deer consume acorns and oak seedlings, and gophers kill many seedlings by girdling and chewing oak roots (White 1966; Griffin 1970, 1977).

Fifty years ago, Bauer (1930) observed in the Tehachapi Mountains, "grazing explains the openness of the understory and ... absence of young growth generally in oak communities... the very young oaks being readily grazed" (p. 279). Studying the vegetation of the San Luis Obispo quadrangle, Wells (1962) found oak seedlings everywhere absent, except occasionally outside fences, and pointed to heavy cattle stocking to account for the poverty of oak reproduction. In the Santa Ana Mountains, Snow (1972) found that browsing and trampling by cattle destroyed all unprotected seedlings of coast live oak and Engelmann oak (Q. engelmannii) in open habitats. He observed that the absence of grazing in the area between 1895 and 1905 corresponded to a period of successful reproduction of these species. Observing oak reproduction on 50,000 acres (20,000 ha) at heavily grazed Hunter Liggett, Fieblekorn found seedlings of valley oak and blue oak exceedingly rare, and those of coast live oak present on

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[7/] Rossi, R.S. (1974) Paso Robles area almond orchard promotion 1910-1925. Unpublished manuscript. 45 p.

[8/] San Francisco Examiner-Chronicle, September 12, 1976.

only about 2,000 acres (800 ha).[9] Over an area as large as the Santa Lucia Mountains, Griffin (1976) found a general absence of valley oak seedlings more than one year old and saplings less than 50 years old. Holland (1976) has made the same observation about blue oak throughout its range.

In the blue oak foothill woodlands, ranchers have been clearing oaks and digger pine (Pinus sabiniana) for range improvement since about 1940. It was assumed that the removal of these "weed" trees would improve the forage production and therefore the output of meat. The practice became widespread on the east and west side of the Sacramento Valley when inexpensive methods of killing the oaks were developed. The practice was advocated and directed by the Agricultural Extension Service and university advisors (Leonard 1956; Leonard and Harvey 1956; Johnson et al. 1959; Murphy and Crampton 1964; Dal Porto 1965; Brown 1973). Extensive clearing was done in the period 1945-1960, especially of blue oak and live oak in the Sierra foothills and North and Central Coast Ranges. Methods have included bulldozing, burning, girdling, cutting, and chemical treatment with 2,4-D and 2,4,5-T applied in axe cuts, and even broadcast spraying from aircraft.

From 1945 to 1953 some of the clearing was paid for through matching funds by federal programs of the Agricultural Adjustment Administration (now the Agricultural Stabilization and Conservation Service, A.S.C.S.). Beginning in 1945 the A.A.A. offered payments for clearing land for tillage, and in 1947 payments were extended to clearing land for pasture. Though the statistics reflect only the total clearing it appears that counties with large areas of oak woodland were the most active participants. For instance, in 1947, Amador, Calaveras, and El Dorado counties accounted for one-third of the 1,500 acres (600 ha) cleared for pasture (U.S. Ag. Adj. Adm. Annual Reports 1944-53). From 1948 to 1952 six central Sierra counties (Amador, Calaveras, El Dorado, Placer, Tuolomne, and Mariposa) accounted for over 50 percent of the 110,000 (44,000 ha) acres cleared for range. San Luis Obispo Co. lost over 6500 acres (2600 ha) of oak savanna and woodland under these programs. In Tehama County, where clearing was most extensive, the A.S.C.S. Director estimates that during the last half of the 1950's through the 1960's, blue oak trees were removed from 90,000 acres (36,000 ha). Herbicides were used on about 5,000 acres (2,000 ha), but in these areas subsequent resprouting has reversed the clearing effort.[10] [11]

It was not until 1973 that the practice of clearing oaks from rangeland was seriously questioned. Holland (1973) working in oak savanna sites near Madera, in the Temblor Range, in Kern County, and at Hastings Reservation in Carmel Valley, showed that forage production and nutritional quality are greater under the blue oaks than between them. Further, the forage has greater nutritional value and remains greener into the dry season; the trees also modify the micro-climate and improve range land soils. Further details of this blue oak canopy effect and its implications for oak clearing appear in Holland (1980) and Holland and Morton (1980). Where oaks form a nearly closed canopy (120-200 trees per acre) tree removal has reportedly not affected forage value in some areas (Murphy and Crampton 1964) and enhanced it in others (Johnson et al. 1959).

RIPARIAN OAKS

The riparian forests of the Central Valley, in which valley oaks were a conspicuous element, have undergone a complete transformation, most having disappeared without description. Captain Sir Edward Belcher, visiting the Sacramento Valley about 1840, said of the forests lining the river: "Within, and at the verge of the banks, oaks of immense size were plentiful. These appeared to form a band on each side, about three hundred yards in depth, and within (on the immense park-like extent, which we generally explored when landing for positions) they were seen to be disposed in clumps, which served to relieve the eye, wandering over what might otherwise be described as one level plain or sea of grass" (Belcher 1843). Based on historical accounts of the Sacramento Valley there were about 775,000 acres (310,000 ha) of riparian woodland in 1850. By 1952 only about 20,000 acres (8,000 ha) remained. Today the estimate is 12,000 acres (McGill 1975; Dutzi 1979). Thompson (1961) in his study of the Sacramento Valley concluded that the riparian forests were effaced during the first two or three decades of Anglo-American occupance. Cronise (1868) recognized large-scale destruction of riparian forests by 1868 in Colusa,

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[9] Fieblekorn, C. (1972) Interim report on oak regeneration study. Unpublished report on file, Natural Resources Conservation Office, Fort Hunter Liggett, Jolon, California, 23 p.

[10] Personal communication, A. Cornell, Agricultural Stabilization and Conservation Service, Davis, California.

[11] Personal communication, R. Christianson, Agricultural Stabilization and Conservation Service Advisor, Tehama County, California.

Yuba, Solano, and Sacramento Counties. At Knight's Landing, huge quantities of cordwood were loaded onto the numerous steamboats navigating the Central Valley rivers during the mining days (Thompson 1961). Agricultural land uses, especially orchards on the broad natural levees, displaced further miles of gallery forests.

Tree removal was also incidental to flood control projects and levee construction. The construction of Shasta Dam by the U.S. Bureau of Reclamation in the mid 1940's caused landowners to respond to dramatically reduced flood and erosion dangers on low lying alluvial soils. Moving onto the floodplain, they converted much riparian vegetation to permanent cropland and orchards (McGill 1975). During the period 1952-1972 over 50 percent of the high terrace riparian vegetation on the margins of the Sacramento River was converted to other uses, especially new orchards (13,100 acres (5,240 ha))(McGill 1975).

Valley oaks have been killed indirectly in some areas by greatly lowered water tables created by water impoundment in the foothills and local ground water pumping; in other areas the accumulation of saline irrigation runoff has been equally destructive.

In the Sacramento Valley, local concern for the continuing loss of riparian habitat has been manifested in a workshop and several conferences (e.g., Sands 1977). At the state level, the Secretary for Resources has established the Upper Sacramento River Task Force whose work includes specific interest in diminishing riparian vegetation.

FIRE SUPPRESSION

Fire suppression policies of the last 50 years have resulted in the unnatural build up of fuels in oak woodland communities. The absence of frequent low intensity fires has permitted the invasion of chaparral species, or highly flammable conifers into the understory (Dodge 1975; Griffin 1976). Overgrazing has aggravated the situation by eliminating ground cover to carry low intensity burns. When fires do start, the oaks are consumed in the conflagration unless they are protected in a canyon bottom or by rocky outcroppings. In San Diego County, Dodge (1975) noted that an oak woodland between Pine Valley and Corte Madera that was "fairly open" in 1931 had become covered with a dense understory of brush. When the 1970 Laguna Fire burned through, approximately 50 percent of the oaks were killed, and the remainder extensively damaged. He concluded that high intensity fires are having the effect of converting oak woodlands to pure chaparral stands. In the 1977 Marble Cone fire, the valley oaks in the area of Chews Ridge which had not burned in almost fifty years, were greatly damaged where Coulter pines (Pinus coulteri) had invaded. Griffin (1980) found 47 percent of the valley oaks were killed in the areas of crown fire and that the thicket of pine saplings and litter had greatly increased the fire hazard to the oaks.

URBANIZATION

Since 1945 the most conspicuous impact on California's oaks has resulted from the growth of cities and suburbs. At both ends of "El Camino Real" huge population centers have grown up. In the Los Angeles basin where Engelmann oak used to be extensive between Pasadena and Claremont, no intact woodland remains in the path of suburban growth (Griffin 1977). Cities named for their oaks, such as Thousand Oaks, Sherman Oaks and Encino, are often left only with token examples of their natural heritage in order to accommodate growth and development. Around San Francisco Bay, there are few oaks in Oakland, very few left among the suburbs filling in the Livermore Valley, and even fewer in the Santa Clara Valley. Between San Jose and Redwood City, Cooper (1926) found a "more or less skeletonized form" of what was "originally a continuous belt of oak forest" on the alluvial fans that reach the bay. Observing this same area in 1798, Captain George Vancouver compared it to a well kept park planted with huge oaks, and added prophetically, it "required only to be adorned with the neat habitations of an industrious people" (Vancouver 1798). These people certainly have come; the area today numbers over one million people in ten cities and endless suburbs, shopping centers and freeways.

Very often, of course, where urban areas have developed, oaks were originally cleared for agriculture. Yet, where they were spared it is paradoxical that now in large and small cities alike, they fare so poorly and are so little revered. However susceptible oaks are to cutting, grazing and other rural pressures, they succumb just as quickly to overwatering, blankets of asphalt, grade changes and pruning. As parcel sizes become smaller, and the land uses intensify, it becomes less likely that viable oak communities will persist on the metropolitan fringes. Often, in fact, the new suburban residential uses put greater pressures on the native plants than did the previous agricultural uses. Horses and cattle in "backyard" corrals are typically overstocked. Home owners cut and disk weed from their property and also often from the roadsides. In the foothill woodland, land for residential uses includes areas that were too steep or inaccessible for farming; now even these waste places have lost their protected status. Seedling oaks are treated as weeds, and the heavily manicured gardens and public parks are filled with non-native plants.

Many cities have adopted tree ordinances primarily intended to save their remaining oaks, as for example in Visalia, Menlo Park and San Luis Obispo. Unfortunately, the fine for cutting a two-hundred-year-old oak is generally far less than the value of the cordwood from the tree.[12/] County-wide tree ordinances pertain only to incorporated cities, and therefore exempt the vast rural areas and unincorporated suburbs. Steinhart (1978) observed that the luxury of fine healthy groves of oak seem to be the sole possession of the most exclusive and expensive communities, such as Brentwood, Beverly Hills, Montecito, Atherton, Woodside and Piedmont.

SUMMARY

In a brief span of time, modern man has made impacts on California oaks which will affect their distribution and abundance for centuries to come. This stands in contrast to the gentle tenancy of the native Indians.

The oaks in the riparian woodlands have suffered the most extensive losses. Almost everywhere, the range of valley oaks has been seriously reduced and the remaining tracks are largely barren of seedlings. In the foothills, hundreds of thousands of acres of blue oak have been converted to grassland and crops, and grazing activity inhibits oak regeneration in the remaining woodland. Until recently, oaks were cut in the state for charcoal production, but currently fuelwood accounts for the bulk of cutting. In Southern California Engelmann oak and coast live oak have been displaced by suburban growth. Approximately 10 million board feet of oaks are cut each year for manufactured products, most of it being California black oak from Northern California.

The clearing of oaks and the impairment of reproduction indirectly affects wildlife populations, soil development, and the ecosystem in general. The landscape is impoverished both in a visual sense and in terms of its natural diversity. It is slowly losing its appeal, its distinction, its uniqueness. Although the individual species of oak are not likely to become extinct, human use has fragmented the handsome oak landscape, and the unique character of many oak communities is already gone or frozen in premature senescence.

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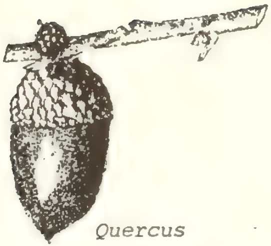

Quercus engelmannii

Taxonomy of California Oaks[1]

John M. Tucker[2]

Abstract: The indigenous oaks of California belong to two genera: *Lithocarpus* and *Quercus*. The main differences are tabulated. The Californian species of *Quercus* belong to three subgenera: the white oaks (subgenus *Quercus*), the black or red oaks (subgenus *Erythrobalanus*), and the intermediate oaks (subgenus *Protobalanus*). The major differences are given in a table. Emphasis in this paper is not on identification, but on hybridization between species, which sometimes complicates identification. Three hybrid complexes are discussed: *Quercus douglasii* X *Q. turbinella* subsp. *californica*, *Q. dumosa* X *Q. lobata*, and *Q. dumosa* X *Q. engelmannii*. An annotated list of species, varieties, and hybrids is included.

INTRODUCTION

Separating tanoak and other oaks

The oaks indigenous to California represent two different genera in the family Fagaceae. The tanoak, or tanbark-oak, *Lithocarpus densiflorus*, is the only North American member of its genus which is represented in eastern and southeastern Asia by about 300 species. All the other Californian oaks belong to the genus *Quercus*.

To the casual observer the tanoak looks quite oak-like, and in fact botanically it was first named as a species of *Quercus*--*Q. densiflora*. The two are, nevertheless, very distinct genera. As a practical field character, the acorn cup of *Lithocarpus densiflorus* is unmistakably different from any of our native species of *Quercus*, having long, recurved cup scales that give the cup a bur-like appearance. However, this is not a generic difference. Their principal generic differences are summarized below:

Lithocarpus	*Quercus*
♂ and ♀ flowers borne either in separate inflorescences, or often in *the same inflorescence* -- with the ♀ at the base, and the ♂ above.	♂ and ♀ flowers borne only in *separate inflorescences*.
the inflorescence is a *stiff spike*, or in some species a panicle.	♂ inflorescence is a slender, *pendulous catkin*.
flowers usually arranged in *small clusters* (3 to 7 in a cluster) along the spike, in axils of small *persistent bracts*.	flowers arranged *singly* along the axis of the inflorescence, the *bracts soon deciduous*.
geographic distribution: eastern and southeastern Asia, from Japan to the Himalayas, with 1 species in western North America.	world-wide in the Northern Hemisphere.

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Oak subgenera

Considering the "true oaks" -- the genus Quercus -- our Californian species fall into three distinct groups, which are classified as three subgenera. (European botanists, however, classify them somewhat differently, as does Rehder, in his well-known "Manual of Cultivated Trees and Shrubs", 1947). These are (1) the white oaks (subgenus Quercus, or synonym Lepidobalanus), (2) the black or red oaks (subgenus Erythrobalanus), and (3) the intermediate oaks (subgenus Protobalanus). The white oaks occur around the world in the Northern Hemisphere; the black oaks occur only in the New World -- North and Central America, and extreme northern South America; and the intermediate oaks -- a small group of only five species -- are restricted to western North America.

The black oaks and white oaks have long been recognized as very distinct groups. The intermediate oaks, however, have usually been placed (as a small group of closely related species) in the white oaks, especially in older classifications. They are not really intermediate in most morphological characters; rather, in some features they resemble the white oaks, but in others they are more like the black oaks. The characteristics that distinguish the three groups are presented in table 1.

The most reliable difference for distinguishing the white oaks from the black oaks is the character of the inner surface of the acorn shell. In the white oaks this is glabrous or essentially so, while in the black oaks it is conspicuously tomentose. The condition in the intermediate oaks varies from one species to another. In Q. dunnii it is densely tomentose; in Q. vaccinifolia it is only very lightly so; and in Q. chrysolepis, the most common and widely distributed species in the group, it varies from moderately to densely tomentose. Mature acorns are not found till late summer or fall, of course, which to some extent limits the usefulness of this character for making field distinctions. Also, it is a character of less importance in the intermediate oaks because of its variability. Nevertheless for distinguishing the black oaks from the white oaks, this is the most constant difference one can find.

In most of the other differences listed in table 1, occasional exceptions may be found. Hence it is always safer to check several of these characters rather than try to rely on a single difference. For example, in the white oaks the acorns mature in 1 year, while in the other two subgenera 2 years are required -- i.e. the acorns do not mature till the end of the second growing season. The coast live oak (Q. agrifolia) -- one of the three native California black oaks -- is one of the very few exceptions, maturing its acorns in only one season.

In addition to the differences listed in table 1, others could be mentioned in chemical constituents of acorns, and host preferences of oak gall wasps (Family Cynipidae). Although these are hardly useful as field characters, they follow a similar pattern to the characters in table 1, and thus reinforce the validity of dividing the New World oaks into three distinct subgenera.

Objectives

My objectives in the remainder of this paper are (1) to point out a problem that sometimes makes field indentification difficult -- namely, hybridization between species, (2) to indicate the species, varieties, and hybrids I recognize (in an annotated list), and (3) to give explanations for several names that have been sources of confusion. Regarding interspecific hybridization, although it may be a rather infrequent, or even rare, phenomenon in many parts of California, in certain areas it has been so extensive as to create a major problem in identification. I will discuss several such examples. The problematic names to be explained are either cases of synonymy (e.g., an older manual using a name no longer considered valid), or names not often seen in manuals (valid or otherwise) by virtue of their obscurity, or uncertainty on the part of the author.

It is not my objective to provide a ready means of identification of the oaks of California -- hence, I have not included a key, or detailed descriptions or illustrations of individual species. Either of two well-known manuals should be adequate for purposes of identification: "A California Flora" (Munz 1959, and supplement 1968) and "A Flora of Southern California" (Munz 1974). Also, where I have discussed the distributions of individual species, this has been only in general terms. For detailed statements of geographic ranges, and excellent distribution maps (for at least the arborescent oaks), the reader is referred to "The Distribution of Forest Trees in California" (Griffin and Critchfield 1972).

Table 1. Morphological Differences Between the 3 Subgenera of New World Oaks

Morphological Character	White oaks (Subgenus *Quercus*)	Black, or Red Oaks (Subgenus *Erythrobalanus*)	"Intermediate" Oaks (Subgenus *Protobalanus*)
trunk bark of mature trees	usually light gray or brown	usually dark brown or blackish	light grayish-brown
wood			
heartwood	light brown or yellowish brown	reddish-brown	light brown
tyloses in vessels	tyloses present in the summer wood vessels	tyloses usually absent in summer wood vessels	tyloses present
leaves	lobes or teeth usually rounded, and without bristle tips	lobes or teeth usually pointed, and often bristle-tipped	teeth pointed, not bristle-tipped but spinose to mucronate
♀ flowers	styles short, with broad stigmas	styles elongated, narrow	styles short, with broad stigmas
♂ flowers	perianth deeply parted; stamens ca. 6-9; anthers notched at apex	perianth cup-shaped, with united parts; stamens ca. 6; anthers usually mucronate at tip	perianth deeply lobed; stamens ca. 8-10; anthers pointed at tip
acorns			
acorn shell	glabrous on inner surface	densely tomentose on inner surface	from densely tomentose to almost glabrous (depending on the species)
abortive ovules	at the base of the mature seed (within the acorn)	apical (rarely lateral, or even basal)	lateral
maturation	annual	mostly biennial	biennial
cup scales	corky-thickened at base (to some degree)	thin and flat	mostly thickened to some degree

HYBRIDIZATION IN CALIFORNIA

Infrequent hybrids

People familiar with the oaks are aware that natural hybrids, between certain species at least, are fairly common. Nevertheless, only species in the same subgenus are involved in natural crosses. No authentic instances are known of natural crosses between members of different subgenera. Thus, they are clearly three distinct groups genetically.

Over the country in general, many different natural hybrids are known -- sometimes between very different species (but always members of the same subgenus). The hybrids are usually quite infrequent and occur as single, isolated trees growing with the parent species. In California, also, this is the usual pattern. Several examples could be cited; the most widely distributed, and probably the most widely known is the oracle oak (*Q.* X *morehus*), a cross between the California black oak (*Q. kelloggii*) and interior live oak (*Q. wislizenii*). It has been known the longest of any of the Californian hybrids, having been first described and named in 1863. Other hybrids known only as rare, isolated individuals are the following:

California black oak (*Q. kelloggii*) X coast live oak (*Q. agrifolia*)
valley oak (*Q. lobata*) X Engelmann oak (*Q. engelmannii*)
valley oak (*Q. lobata*) X Oregon oak (*Q. garryana*)
valley oak (*Q. lobata*) X desert scrub oak (*Q. turbinella* subsp. *californica*)
Oregon oak (*Q. garryana*) X scrub oak (*Q. dumosa*)
Oregon oak (*Q. garryana*) X leather oak (*Q. durata*)
Brewer oak (*Q. garryana* var. *breweri*) X deer oak (*Q. sadleriana*)

These are usually found growing with the parental species, and, to the critical eye, are morphologically intermediate. They are often demonstrably fertile, setting sizeable crops of viable acorns. Nevertheless, back-crosses or F_2's are not commonly found. Usually it is just the single, isolated first-generation (F_1) hybrid. They are often puzzling to the non-taxonomist, however, because of their unusual characteristics and their rarity. But once they have been critically compared with the species with which they are growing -- and perhaps others in the area -- their true identity can usually be determined. Beyond this initial question of their identity, therefore, they ordinarily pose no real *taxonomic* problems.

Examples of extensive regional hybridization

Another series of hybrids do, however, pose a more important taxonomic problem. These are cases at the other extreme in which hybridization has been so extensive that over sizeable areas the populations consist mainly of highly variable intermediate types, with only an occasional individual identifiable as one or the other parental species. When the differences between the species are "blurred" in this way, botanists have sometimes classified them as mere varieties of a single species -- especially when the species involved are quite similar anyhow. *Quercus dumosa* and *Q. turbinella* provide an example of this sort.

One botanist has coined the term "semispecies" for groups of this sort. Unfortunately, there is no simple taxonomic solution for all such cases. The degree of difference between the species involved, and the extent of hybridization between them, can vary considerably from one example to another.

1. *Quercus douglasii* X *Q. turbinella* subsp. *californica*

The most extensive hybrid complex in California, *Quercus* X *alvordiana*, involves the blue oak (*Q. douglasii*) and desert scrub oak (*Q. turbinella* subsp. *californica*). These oaks are quite different morphologically and ecologically, and in large part have different geographical ranges.

The blue oak is a small to medium-sized deciduous tree, 20-30 ft. (6-10 m.) in height. The leaves are dull bluish-green, 1-2 1/2 in. (2.5-6 cm.) long, shallowly lobed or coarsely toothed (or entire), with rounded or obtuse lobes or teeth. It is common on dry interior foothills and lower mountain slopes from the Tehachapi Mountains northward, forming an open woodland sometimes in pure stands, but commonly associated with digger pine (*Pinus sabiniana*) and often with interior live oak (*Q. wislizenii*).

The desert scrub oak is commonly a shrub, 6-15 ft. (2-5 m.) in height, or sometimes a small shrubby tree. Evergreen in habit, the small grayish-green leaves are 1/2-1 1/2 in. (1.5-4 cm.) long, with spinose or mucronate teeth on the margins. It occurs in pinyon-juniper woodland or in pure stands forming an open chaparral on arid mountain slopes along the southwestern border of the Mohave Desert, and northwestward to northern Ventura and Santa Barbara counties and southeastern San Luis Obispo County.

Quercus turbinella, in common with a number of other Mohavean species, extends northwestward through the very dry Inner South Coast Ranges as far as southern San Benito County. Throughout this region it hybridizes freely with blue oak, forming variable populations, with most individuals being intermediate in varying degrees between the parents. More localized hybridization has also occurred in areas on the west side of the upper Salinas Valley and in the northeastern Tehachapi's, e.g., along Oak Creek.

The well-known botanist of the early 1900's, Alice Eastwood, was the first to make collections from any of these variable populations. In 1894, in San Emigdio Canyon, Kern County, to the north of Mt. Pinos, she made a series of collections ranging from small-leaved shrubs to larger-leaved trees. And she may have surmised that the extreme local variation was the result of hybridization. Nevertheless, a few years later she described a "new species" based on one of her collections, naming it *Quercus alvordiana* (Eastwood 1905).

For many years afterward this name was a source of confusion to California botanists, doubtless because of the extreme variation at the type locality and elsewhere in that region. Every one of several manuals or floras in use prior to 1959 (when Munz published "A Flora of California") interpreted *Quercus alvordiana* differently. One treated it as a distinct species (Abrams, "Illustrated Flora of the Pacific States"); one reduced it to a variety of *Q. dumosa* (Jepson, "A Manual of the Flowering Plants of California"); a third was reluctant to express any opinion (Sudworth, "Trees of the Pacific Slope"); and a fourth felt it was not worthy of recognition at all (McMinn, "Illustrated Manual of California Shrubs"). McMinn noted, however, that blue oak hybridizes with scrub oak in the Inner South Coast Ranges. (He considered *Q. turbinella* merely a form of *Q. dumosa*).

I made a study of the "*Quercus alvordiana* problem", as a Ph.D. research project and concluded that this whole complex was the result of long-continued hybridization between *Q. douglasii* and *Q. turbinella* (Tucker 1950, 1952). And more recently, a very detailed study was made of a series of variable populations on hillslopes facing different directions at a single general location (Benson, et al. 1967). This showed that on the dry southwest-facing hillslope the population, although variable, was composed mainly of shrubby *turbinella*-like types, while on the more protected northeast-facing slope, types more similar to *Q. douglasii* predominated. Thus, each microsite was selecting in a very sensitive fashion the best adapted types from the genetically variable population.

2. *Quercus lobata* X *Q. dumosa*

The highly variable oak on the southern California islands called *Quercus macdonaldii* is generally recognized today as a complex derived from hybridization between the valley oak (*Q. lobata*) and scrub oak (*Q. dumosa*). It was originally described as a species, however, by E. L. Greene (1889), from Santa Cruz Island. It is also known from the neighboring Santa Rosa Island, and from Santa Catalina Island; also from several mainland localities, from Santa Barbara County (Smith 1976) to Orange County (Boughey 1968).

Quercus macdonaldii was described by Greene as "a small deciduous tree, from fifteen to thirty-five feet high", but later botanists noted that it sometimes intergraded with the shrubby evergreen scrub oak, common both on Santa Catalina and on the Northern Channel Islands. Accordingly, Jepson (1925) reduced *Q. macdonaldii* to a variety of *Q. dumosa*. Others (Sargent 1895, Sudworth 1908) had considered it merely a form of *Q. dumosa*, not worthy of taxonomic recognition.

On the other hand, the similarity of *Q. macdonaldii* to *Q. lobata* apparently went unnoticed until Hoffmann (1932), who botanized extensively on the islands off Santa Barbara, took exception to Jepson's treatment: "....if it [*Q. macdonaldii*] is not a distinct species, it seems to the writer to be much more closely related to *Q. lobata* than to *Q. dumosa*." With increased botanical interest in the southern California islands in recent years, the *Q. macdonaldii* complex has been brought into sharper focus: "*Quercus lobata* Née occurs on Santa Cruz and Santa Catalina islands and is genetically represented on Santa Rosa, Santa Cruz, and Santa Catalina where it has hybridized freely with *Q. dumosa* to produce a variable population to which Greene applied the name *Q. macdonaldii*" (Muller 1967).

One complicating factor is the fact that Q. douglasii also occurs in a few small groves on Santa Cruz and Santa Catalina islands (Muller, 1967), and a single tree of Q. engelmannii on Santa Catalina (Thorne 1967). These oaks apparently have also hybridized with Q. dumosa, and their backcrosses to the scrub oak may be difficult to distinguish from macdonaldii backcrosses.

The infrequent mainland occurrences of hybrids have usually been isolated F_1s. However, in at least one location known to the writer in the Santa Barbara area, an F_1 occurs with Q. dumosa and a number of variable dumosa-like intermediates. Interestingly enough, most of the known occurrences on the mainland are at -- or even beyond -- the southern limits of the range of Q. lobata.

3. Quercus engelmannii X Q. dumosa

In southern California (aside from the insular Q. X macdonaldii) the most frequent and conspicuous examples of hybridization are those involving Q. engelmannii and Q. dumosa. These are very different species: Q. engelmannii is a tree 25-35 ft. (7-10 m.) in height, with semipersistent leaves oblong to oblong-ovate, with margins entire or nearly so, bluish-green and often glaucous, up to about 2-2 1/2 in. (5-6 cm.) long. Quercus dumosa is an evergreen shrub with usually mucronate-dentate leaves quite variable in shape, but green and slightly to moderately glossy above, and mostly about 1/2-1 in. (1.5-2.5 cm.) long. Engelmann oak is a dominant tree in the southern oak woodland, occurring on deeper soils along the base of the San Gabriel Mountains in the Pasadena area, and extending southeastward into northern Baja California. The scrub oak is a wide-ranging chaparral shrub common on the drier, more shallow soils of lower mountain slopes.

Where stands of oak woodland occur adjacent to chaparral, the two oaks have hybridized freely, producing "hybrid swarms", the members of which show varying combinations of the parental characters. Also, in this general region stands of scrub oak often have leaves distinctly suggestive of Engelmann oak, i.e., somewhat larger and more oblong than usual, with more nearly entire margins, etc. In such stands one may see larger, more arborescent shrubs 10 to 15 ft. (3 to 5 m.) in height, rising above the surrounding chaparral. As Benson (1962) has pointed out, the trend toward a drier climate in southern California has favored chaparral species, and some former stands of oak woodland have disappeared. Thus, although Quercus engelmannii is no longer present, its genes remain in the remnants of hybrid swarms which are now being absorbed by repeated backcrossing to Q. dumosa.

As so often happens with oak hybrids, those between Q. engelmannii and Q. dumosa have been a source of some taxonomic confusion. The names, Quercus dumosa var. elegantula (Greene) Jepson and Quercus grandidentata Ewan, both apply to such hybrids. In each case, of course, the botanist who first published the name thought he had discovered a "new", previously unnamed, oak.

In the case of Q. dumosa var. elegantula (originally described by E. L. Greene as Q. macdonaldii var. elegantula), Greene realized his error when he re-visited his type locality (Temecula Canyon) at a later date. He noted that Q. engelmannii and Q. dumosa were abundant in the area and hybridizing freely, and acknowledged that he had described one of the hybrids. Quercus grandidentata, similarly, was described from a tree in a hybrid swarm -- this one in Monrovia Canyon -- although this fact was not realized originally. However, later study by Prof. Lyman Benson and his students, of Pomona College, demonstrated this beyond any doubt. In 1949, and again in 1951, students planted acorns from the type tree. In both groups of seedlings scarcely any two were alike, and individuals ranged in leaf characters from those resembling Q. engelmannii to those resembling Q. dumosa (Benson, 1962).

ANNOTATED LIST OF SPECIES AND HYBRIDS

The following list includes the species of Quercus native to California, and their natural hybrids. When a hybrid has been formally named with a binomial, this is also listed. Synonyms are included, and occasional nomenclatural notes in an attempt to clarify obscure or questionable names.

White Oaks (Subgenus Quercus)

1. Quercus douglasii Hook. & Arn. (Q. ransomi Kell.; Q. oblongifolia brevilobata Torr.)

   Blue Oak

Hybrids:

- *Q. douglasii* X *Q. dumosa*
- *Q. douglasii* X *Q. garryana* : *Quercus* X *eplingi* C.H. Muller
- *Q. douglasii* X *Q. lobata* : *Quercus* X *jolonensis* Sarg.
- *Q. douglasii* X *Q. turbinella* ssp. *californica* : *Quercus* X *alvordiana* Eastwood (*Q. dumosa* var. *alvordiana* (Eastw.) Jeps.) (See detailed discussion in preceding section.)

2. *Quercus dumosa* Nutt. (*Q. berberidifolia* Liebm.; *Q. acutidens* Torr.; *Q. dumosa* var *acutidens* S. Wats.)

Scrub Oak

Hybrids:

- *Q. dumosa* X *Q. douglasii*
- *Q. dumosa* X *Q. durata*
- *Q. dumosa* X *Q. engelmannii* : *Quercus* X *grandidentata* Ewan (*Q. macdonaldii* var. *elegantula* Greene; *Q. dumosa* var. *elegantula* (Greene) Jeps.) (See detailed discussion in preceding section.)
- *Q. dumosa* X *Q. garryana* : *Quercus* X *howellii* Tucker
- *Q. dumosa* X *Q. lobata* : *Quercus* X *macdonaldii* Greene (*Q.* X *townei* Palmer; *Q. dumosa* var. *kinselae* C.H. Muller) (See detailed discussion in preceding section.)
- *Q. dumosa* X *Q. turbinella* spp. *californica*

3. *Quercus durata* Jeps. (*Q. dumosa* var. *bullata* Engelm.; *Q. dumosa* var. *revoluta* Sarg.)

Leather Oak

Hybrids:

- *Q. durata* X *Q. dumosa*
- *Q. durata* X *Q. garryana* : *Quercus* X *subconvexa* Tucker

4. *Quercus engelmannii* Greene

Mesa Oak, Engelmann Oak

Hybrids:

- *Q. engelmannii* X *Q. dumosa* : *Quercus* X *grandidentata* Ewan (*Q. macdonaldii* var. *elegantula* Greene; *Q. dumosa* var. *elegantula* (Greene) Jeps.) (See detailed discussion in preceding section.)
- *Q. engelmannii* X *Q. lobata*

5. *Quercus garryana* Dougl. (*Q. neaei* Liebm.)

Oregon Oak

Hybrids:

- *Q. garryana* X *Q. douglasii* : *Quercus* X *eplingi* C.H. Muller
- *Q. garryana* X *Q. dumosa* : *Quercus* X *howellii* Tucker
- *Q. garryana* X *Q. durata* : *Quercus* X *subconvexa* Tucker
- *Q. garryana* X *Q. lobata*

Varieties:

var. *breweri* (Engelm. in Wats.) Jeps. (*Q. breweri* Engelm.; *Q. lobata fruticosa* Engelm.; *Q. oerstediana* R. Br. Campst.; *Q. garryana* var. *semota* Jeps.)

Brewer Oak

Hybrids:

- *Q. garryana* var. *breweri* X *Q. sadleriana*

The shrubby forms of *Q. garryana* of the southern Sierra Nevada, Greenhorn Range, and the Tehachapi's, were called var. *semota* by Jepson, supposedly having less tuberculate cup scales than in typical var. *breweri* of the high North Coast Ranges. However, there seems to be no significant morphological difference between the populations of these different regions.

6. *Quercus lobata* Née (*Q. hindsii* Benth.; *Q. longiglanda* Torr. & Frem.)

Valley Oak

Hybrids:

- *Q. lobata* X *douglasii* : *Quercus* X *jolonensis* Sargent

- *Q. lobata* X *dumosa* : *Quercus* X *macdonaldii* Greene (*Q.* X *townei* Palmer; *Q. dumosa* var. *kinselae* C.H. Muller) (See detailed discussion in preceding section.)
- *Q. lobata* X *Q. engelmannii*
- *Q. lobata* X *Q. garryana*
- *Q. lobata* X *Q. turbinella* ssp. *californica* : *Quercus* X *munzii* Tucker

7. *Quercus sadleriana* R. Br. Campst.

Deer Oak

Hybrids:

Q. sadleriana X *Q. garryana* var. *breweri*

8. *Quercus turbinella* Greene (*Q. dumosa* var. *turbinella* (Greene) Jeps; *Q. subturbinella* Trel.)

Desert Scrub Oak

subsp. *californica* Tucker

Hybrids:

- *Q. t. californica* X *Q. douglasii* : *Quercus* X *alvordiana* Eastwood (*Q. dumosa* var. *alvordiana* (Eastw.) Jeps.) (See detailed discussion in preceding section.)
- *Q. t. californica* X *Q. dumosa*
- *Q. t. californica* X *Q. lobata* : *Quercus* X *munzii* Tucker

Intermediate Oaks (Subgenus *Protobalanus*)

9. *Quercus chrysolepis* Liebm. (*Q. fulvescens* Kell.; *Q. crassipocula* Torr.)
Canyon Live Oak, Maul Oak

Jepson named a number of forms (later elevating them to varieties) that supposedly differ in one way or another from typical *Q. chrysolepis*: forma *grandis* (var. *grandis*), forma *hansenii* (var. *hansenii*), forma *nana* (var. *nana*), forma *pendula* (var. *pendula*). Aside from the var. *nana*, however, these are scarcely worthy of taxonomic recognition.

Hybrids:

Q. chrysolepis X *Q. tomentella*

Q. chrysolepis X *Q. vaccinifolia*

In the mountains of central and southeastern Arizona, *Q. chrysolepis* hybridizes freely with *Q. dunnii*. In California, however, they are completely isolated ecologically.

Varieties:

var. *nana* Jeps.

This name has been applied to almost any shrubby form of *Q. chrysolepis* throughout its range. Munz' (1959) suggestion that this variety is "possibly a hybrid with *Q. vaccinifolia*" may well apply to shrubby forms found at higher elevations in the Sierra Nevada, but not to the numerous chaparral forms throughout the Coast Ranges and the mountains of southern California (Myatt 1975).

10. *Quercus dunnii* Kell. (*Q. chrysolepis* subsp. *palmeri* Engelm.; *Q. palmeri* Engelm.)

Dunn Oak (Palmer Oak)

Hybrids: See comment under *Q. chrysolepis*.

The name *Quercus palmeri* Engelm. is used for this oak by some authors; however, strict adherence to the rule of priority (Article 11, International Code of Botanical Nomenclature, 1972) dictates the use of the name *Quercus dunnii* Kell.

Kellogg published the name and original description of *Q. dunnii* in the Pacific Rural Press (a weekly farm newspaper!) in June, 1879. Engelmann, however, had previously named another collection of this oak *Quercus palmeri* in 1877; but in doing so, he designated it a subspecies of *Q. chrysolepis* -- not a distinct species. Although he did elevate it to full specific rank in a later publication (October, 1879), this was 4 months after Kellogg published *Q. dunnii*.

11. *Quercus tomentella* Engelm.

Island Oak

Hybrids:

Q. tomentella X *Q. chrysolepis*

12. *Quercus vaccinifolia* Kell. (*Q. chrysolepis* subsp. *vaccinifolia* Engelm.)
Huckleberry Oak

Hybrids: *Q. vaccinifolia* X *Q. chrysolepis*

Black or Red Oaks (Subgenus *Erythrobalanus*)

13. *Quercus agrifolia* Née (*Q. acutiglandis* Kell.; *Q. pricei* Sudw.)
Coast Live Oak

The name *Quercus pricei* Sudworth has long been a source of confusion to Californian botanists. In my judgment it is best considered a synonym of *Q. agrifolia*.

The type specimen of *Quercus pricei* (Geo. B. Sudworth Aug. 20, 1904, U.S. National Herbarium No. 1583367) is clearly *Q. agrifolia* in most characteristics: the acorns are annual in maturation -- not biennial, as stated by Sudworth (1907, 1908), the leaves are slightly to moderately convex above, and on the under side usually bear tufts of pubescence in the axils of the secondary veins. Some of the leaves, however, are slightly more pointed apically than is typical for *Q. agrifolia* -- in this character they are slightly suggestive of *Q. wislizenii*.

A series of 4 collections recently made at the type locality, Dani's Ranch, Monterey County (N.H. Cheatham, 29 Sept., 1978) are all *Q. agrifolia*. None of them showed any indication of hybridity with *Q. wislizenii*, although Cheatham reported that the latter species was in the general area.

Hybrids:

Q. agrifolia X *Q. kelloggii*: *Quercus* X *chasei* McMinn, Babcock, & Righter
Q. agrifolia X *Q. wislizenii*

Varieties:

var. *frutescens* Engelm.
var. *oxyadenia* (Torr.) J. T. Howell

Hybrids:

Q. agrifolia. var. *oxyadenia* X *Q. kelloggii*: *Quercus* X *ganderi* C. B. Wolf

14. *Quercus kelloggii* Newb. (*Q. tinctoria* var. *californica* Torr.; *Q. californica* Cooper; *Q. sonomensis* Benth.)

California Black Oak

Shrubby forms, mostly at higher elevations, were named forma *cibata* by Jepson.

Hybrids:

Q. kelloggii X *Q. agrifolia*: *Quercus* X *chasei* McMinn, Babcock & Righter
Q. kelloggii X *Q. agrifolia* var. *oxyadenia*: *Quercus* X *ganderi* C. B. Wolf
Q. kelloggii X *Q. wislizenii*: *Quercus* X *morehus* Kell.

15. *Quercus wislizenii* A. DC. (*Q. parvula* Greene; *Q. shrevei* C. H. Muller)
Interior Live Oak

Quercus wislizenii is characteristic of the woodland association of *interior* foothills and lower mountain slopes in California, as its common name implies. The species as a whole is rather diverse ecologically, however, and several generally recognizable forms, noted below, are often correlated with specific habitats. These may merit taxonomic recognition, as varieties or subspecies; in fact, names have been applied to some of them.

1. The most prevalent form is the commonly spreading, round-headed tree of interior foothill woodland.

2. A shrubby form is common in chaparral areas and is the prevalent form in the mountains of southern California (var. frutescens Engelm.).

3. A form with unusually large, oblong leaves, which may be a tall tree on the borders of redwood groves, is frequent in the Santa Cruz and Santa Lucia Mountains. The name Quercus shrevei C. H. Muller was applied to a similar form of Q. wislizenii from the Santa Lucia's (Palo Colorado Canyon, Monterey Co., about four miles from the ocean) although it was described as a small tree 4-6 m. tall, with small, evergreen leaves growing scattered in the chaparral of ridgetops (Muller 1938).

4. A shrubby form on Santa Cruz Island was described as Quercus parvula Greene. Munz (1959) treated this name as a synonym of var. frutescens Engelm., the chaparral form of the mainland; but shrubs of this insular form, growing in the University of California Arboretum at Davis, seem distinctly different, having larger, less spiny leaves, larger and more pubescent buds, and more blunt and pubescent acorns. Quercus parvula probably merits recognition as a variety distinct from the var. frutescens.

Mr. Kevin C. Nixon, a graduate student at the University of California, Santa Barbara, is currently making a detailed study of Quercus wislizenii (sensu lato). His views are quite similar to those expressed above.

Hybrids:

Q. wislizenii X Q. agrifolia
Q. wislizenii X Q. kelloggii:
Quercus morehus Kell.

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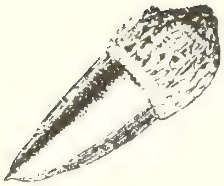

Quercus agrifolia

Natural Hybridization Between Two Evergreen Black Oaks in the North Central Coast Ranges of California[1]

Michael C. Vasey [2]

Abstract: Hybridization between coast and interior live oaks is recognized and appears to be concentrated in the northern portion of their overlapping ranges. A hybrid index analysis of selected populations of these species along a 175-mile north/south gradient confirms this observation, and an examination of the fossil record suggests a reason for this pattern of concentration. After a long period of isolation, ancestors of these two oaks converged during the Middle Pliocene and dramatic oscillations of climate in California since that time provided ample opportunity for hybrid establishment particularly at their range extremes in the north central Coast Ranges. It is suggested that this study could be improved by incorporating Quercus kelloggii into a computerized hybrid analysis of all three species.

INTRODUCTION

Although California's two evergreen black oaks, Quercus agrifolia Née and Q. wislizenii A. D.C., are well recognized species, the possibility of natural hybridization between the two has been minimally investigated and found to exist. Griffin and Critchfield (1972) reported that in Mendocino County, at the northern extreme of Q. agrifolia's distribution, this species seems to hybridize readily with Q. wislizenii so that it is difficult to tell where the coast live oak distribution ends. Well-documented evidence of hybridization between these two species was first published by Brophy and Parnell (1974). By means of a hybrid index analysis, they discovered significant degrees of hybrid activity between four sympatric populations of the two live oaks in Contra Costa County. Although Griffin and Critchfield (1972) mention a senior thesis which focuses on such hybridization in the Santa Cruz Mountains (Thomas 1970), I could not obtain a copy.

This study was motivated by the long-term observations of Dr. G. L. Stebbins, who noted the apparent extensive hybridization in Mendocino and was impressed by the lack of such hybridization in more southerly regions of the Coast Ranges where the two species are sympatric. As Visiting Professor at San Francisco State University, Dr. Stebbins conducted a graduate seminar in which he and nine students attempted to (1) analyse and document the extent of hybridization between selected populations of the two species along an approximate 175 mile transect from southern Mendocino Co. to the San Mateo/Santa Cruz Co. line and (2) investigate the possible causes for greater hybridization in the north than in the south.

METHOD OF STUDY

Two control populations were selected upon which the subsequent hybrid studies were based. The Q. agrifolia controls came from a presumably pure population near San Bruno on the San Francisco Peninsula and the Q. wislizenii controls from a stand in the Sierra Nevada foothills near Ione. Two sympatric localities were sampled, Saratoga Gap and Phoenix Lake, and two less distinct sympatric populations near Hopland in Mendocino Co. were incorporated. These four sympatric populations covered as much of a north to south gradient as was possible within the scope of the survey. Finally, two additional allopatric populations were selected, Q. agrifolia from Hamilton Base and Q. wislizenii from Lake Co. Table 1 provides pertinent data regarding these eight populations.

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[1] Presented at the Symposium on the Ecology, Management and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Graduate student, Department of Ecology and Systematic Biology, San Francisco State University, 1600 Holloway Avenue, San Francisco, California 94132.

We collected population samples in early February, 1978, removing one typical branch from ca. thirty mature trees per locality. These were labeled, sealed, and stored in large plastic bags in a cold storage chamber. We initially evaluated the control samples in terms of the best morphological distinctions between the two species and determined only thirteen characters of potential significance. Each member of our group then scored an equal share of specimens. Concerted efforts were made to unify the group's evaluation of each of the characters. Based upon the accumulated data, Dr. Stebbins selected eight of these characters that provided the most legitimate contrast between the two controls. In view of the small number of characters developed, we analysed the results by means of an Andersonian hybrid index. Three of the characters were deemed of sufficient distinction to merit weighting. Hence a total of eleven values were assigned to each specimen. Table 2 lists the final characters, those weighted, and the values involved in scoring each individual.

The question of geographically differential hybridization was approached by investigating the possibility of more effective reproductive isolation in the south due to different pollination timing mechanisms and by examining the evolutionary history of the two species. The efforts expended in exploring the former did not prove to be particularly fruitful. However, this possibility was not ruled out. Some evidence suggested that the timing of Q. wislizenii's pollination is cued by photoperiod response whereas Q. agrifolia's is not, and this may be a contributing factor in keeping the two species apart in the south where Q. agrifolia may bloom earlier due to thermal response.

Table 1--Population locality data.

Population	Location	Elevation	Plant Associations[1/]	Habit
San Bruno	Junipero Serra Co. Park, off I-280, San Bruno, San Mateo Co.	60 m	Mixed Hardwood F., Q. agrifolia-Arbutus	spreading trees, 10-16 m high
Ione	Off Hwy 88 ca. .8 km east of junction Rte 124, Amador Co.	90 m	Foothill Woodland	small trees, ca. 10 m high
Saratoga Gap	Along Hwy 9, .3-1.8 km SW of Hwy 35, San Mateo/Santa Cruz Co. line	670 m	Mixed Hardwood F., Arbutus-Lithocarpus	varied trees, 3-12 m high
Phoenix Lake	Along Phoenix & Crown Rds., .8 km SE of Phoenix Lake, Marin Co.	180 m	Mixed Hardwood F., Q. agrifolia-Arbutus & Chaparral	varied trees, 3-10 m high
Hamilton Base	Ca. .4 km SW of Hamilton AFB at entrance to Pacheco Valley Ave, Marin Co.	60 m	Mixed Hardwood F. Q. agrifolia-Arbutus	spreading trees, 10-14 m high
Lake County	Along Hwy 175 ca. 16 km E of U.S. 101, Lake Co.	720 m	Chaparral	shrubby trees, 2-4 m high
Hopland Entrance	Ca. .3 km from junction Hwy 175 & rd. to UCD Field Sta., Hopland, Mendocino Co.	240 m	Foothill Woodland/ Northern Oak Woodland	medium trees, 4-10 m high
Hopland Headquarters	Vicinity of Bunkhouse, UCD Field Sta., Hopland, Mendocino Co.	240 m	Foothill Woodland/ Northern Oak Woodland	spreading trees, 6-16 m high

[1/] Plant associations according to Barber and Major (1977).

Table 2--Index values of character states.

Character	*Q. agrifolia* Index Value (1)	*Q. wislizenii* Index Value (2)
1. Length to width leaf ratio	.57 - .79	.33 - .56
2. Number of secondary veins	6 - 11	12 - 22
3. Leaf concavity[1]	+	+/- and -
4. Leaf concavity	+/- and +	-
5. Abaxial hairs[1]	+	+/- and -
6. Abaxial hairs	+/- and +	-
7. Number of trichome rays	8 - 14	5 - 7
8. Max. width of lateral veins[1]	.19 - .40 mm	.07 - .18 mm
9. Max. width of lateral veins	.27 - .40 mm	.07 - .26 mm
10. Mean size ultimate areoles	.020 - .046 mm	.047 - .080 mm
11. Length terminal bud scales	1 - 3.9 mm	4 - 7 mm
Maximum Hybrid Index Values	11	22

[1] Indicates the characters weighted to give double values.

The evolutionary analysis took place in three stages: (1) Dr. Stebbins visited Dr. D. I. Axelrod at U.C. Davis, who provided data regarding all known localities of the presumed fossil antecedents of the two subject species and the approximate dates of the fossil floras in which they were located; (2) all available literature regarding these fossils, their floras and their photographs was reviewed; and (3) Dr. Stebbins and I visited the Department of Paleontology at U.C. Berkeley and consulted with Dr. Howard Schorn and examined key fossils pertaining to the study.

RESULTS

The results of the hybridization analysis are graphically portrayed by histograms (fig. 1) which plot the frequency distribution of the total hybrid index values obtained for each individual sampled per population. The great majority of individuals from San Bruno (86 percent) scored between 11-13 and those from Ione (97 percent) scored from 20-22. These two sets of values were interpreted to represent, respectively, the ranges of variation for pure *Q. agrifolia* and pure *Q. wislizenii*. Individuals possessing scores midway between these two extremes (16-17) were construed to represent F_1 generation hybrid types. Finally, specimens which scored between the extreme and mean values (14-15 and 18-19) were interpreted to represent, respectively, introgressed *Q. agrifolia* types and introgressed *Q. wislizenii* types.

Briefly stated, introgression represents the repeated backcrossing of a natural hybrid to an ecologically dominant parent which results in the introduction of the germ plasm from the less adapted species into the gene pool of the most highly adapted species for the particular environment (Anderson 1949). This process results in progeny which favor the dominant species in a majority of characters but nevertheless reveal a small number of features characteristic of the other parent.

As anticipated, of the four sympatric populations, Saratoga Gap presented the fewest intermediates (16 percent), this number increased dramatically further north at Phoenix Lake (54 percent), and the Mendocino populations were nearly bereft of pure species, possessing 87 percent and 80 percent intermediates at, respectively, Hopland Entrance and Hopland H.Q. In reality, the Hopland H.Q. population did not consist of two sympatric species since none of the individuals scored as pure *Q. agrifolia*. On the other hand, the Hopland Entrance population, which was nearer to the large valley in which the town of Hopland is located, included sympatric individuals of both parental species and appeared to constitute a classic hybrid swarm with few pure species, a large percentage of introgressive types varying in each direction (47 percent) and a significant number (40 percent) of F_1 hybrid types. These findings correlated well with field observations and tend to confirm the suspected north to south hybridization gradient.

The findings with respect to the two allopatric populations (Hamilton Base and Lake Co.) were, on the contrary, quite surprising. Although the habitat and physiognomy of the trees at Hamilton Base strongly resembled the control population at San Bruno, only 33 percent of the population scored in the range of pure *Q. agrifolia* whereas 23 percent scored as introgressive *Q. agrifolia* types and a

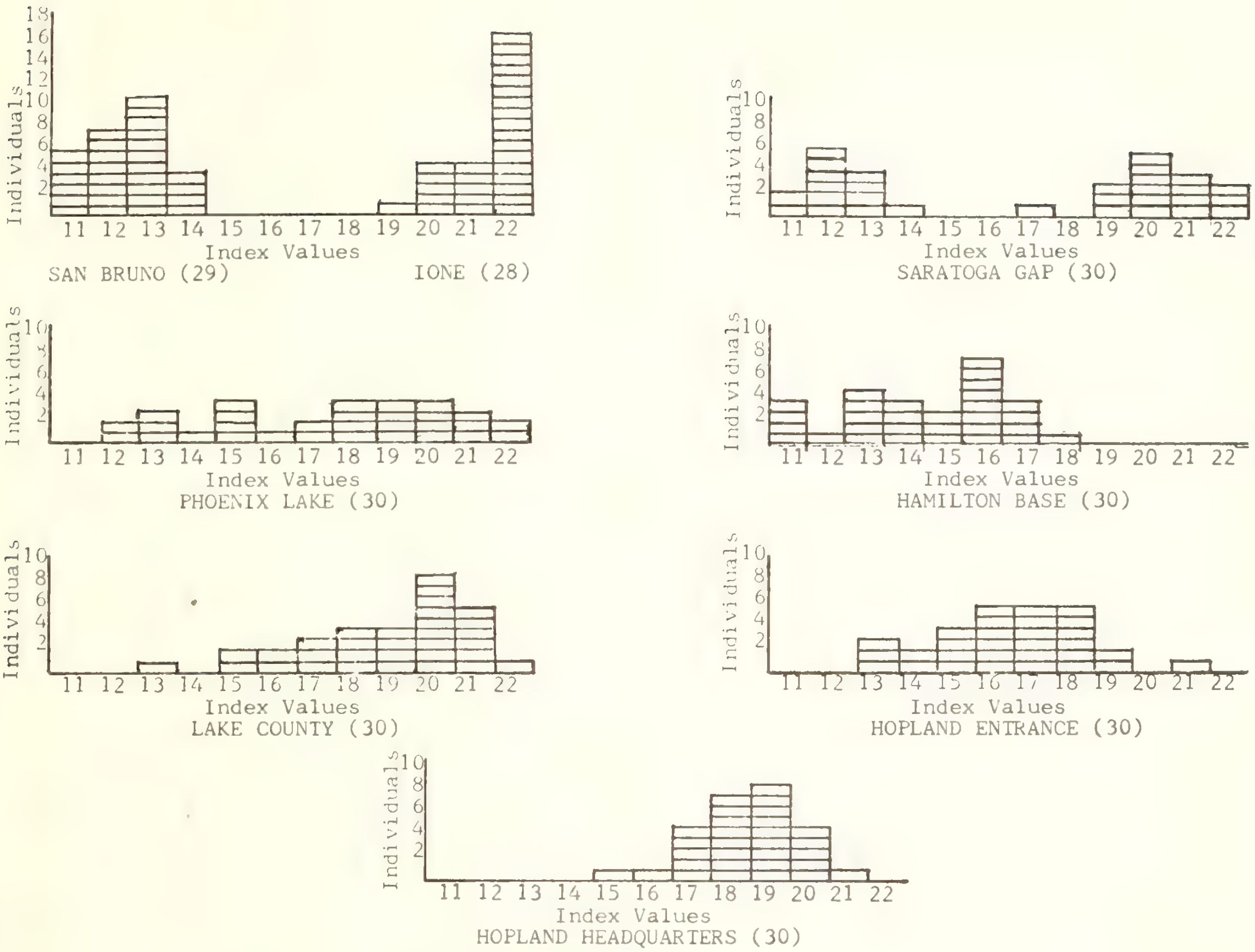

Figure 1--Frequency distribution of hybrid index values with extremes of 11 for Q. agrifolia and 22 for Q. wislizenii.

remarkable 40 percent appeared to represent F_1 hybrid types. Similary, although the Lake Co. population looked like the typical shrubby Q. wislizenii frequently associated with high chaparral throughout the Coast Ranges, the hybrid index values reveal that less than half of the population scored as pure. Since hybrid individuals occur in these populations in spite of the present absence of one of the putative parent species, either these trees represent progeny derived from ancestors which once existed in more sympatric populations and produced fertile hybrids, or some other factor not considered in the present study must account for these results. These two possibilities will be discussed below.

Although the fossil record of Q. agrifolia and Q. wislizenii is not extensive, it does provide certain key insights into the evolutionary history of the two species. A very ancient fossil, Q. distincta Lesq. from the Eocene Chalk Bluffs Flora, has been interpreted to represent an ancestor of Q. agrifolia (MacGinitie 1941). This fossil is ca. 55 million years (m.y.) old[3/] and, according to MacGinitie, was part of a humid, subtropical flora which now finds its closest modern counterpart in the tierra templada of the eastern Sierra Madre Mnts. of Mexico. Thus, a plausible ancestor to Q. agrifolia is documented in the early Tertiary of California, a distinction shared by few other modern elements of California's vegetation.

Over the next thirty-plus million years the fossil record is silent with respect to these species. When evidence of their existence resurfaces in the Miocene, a clear pattern emerges with respect to their status and distribution. The oldest known locality

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[3/] Personal communication, H. Schorn.

for Q. wislizenii's fossil antecedent, Q. wislizenoides, is the Middlegate Flora of western Nevada and the fossils found there clearly demonstrate that Q. wislizenii had completely differentiated by this time and superficially did not differ from the modern species. This fossil flora has been dated at ca. 18 m.y. of age and included many deciduous hardwoods, conifers, and other sclerophyllous trees typical of a mild continental climate. As is demonstrated by the west Sierra Nevadan Remington Hill Flora (ca. 9 m.y. old) and the central Coast Range Mulholland Flora (ca. 7 m.y. old), Q. wislizenoides and several of its Middlegate associates were forced to retreat from the interior west as a result of Sierran uplift and a warmer and drier climate. By the Middle Pliocene, this western migration resulted in Q. wislizenoides being well established in California's Coast Ranges.

Q. agrifolia's recent fossil record is less satisfactory but, as indicated by the reported existence of its fossil relative, Q. lakevillensis, in the 12 m.y. old Mint Canyon and the 7.5 m.y. old Mt. Eden Floras, it then apparently existed in a frostless, subhumid association which prevailed over much of southern California. Axelrod (1977) has compared this association, characterized by avocado, palm, laurel and other sclerophylls, to the so-called hammock flora of Florida. The fossil record suggests that this flora, and a contemporaneous coastal closed-cone conifer forest of which Q. lakevillensis was most likely a member, moved up along California's coast during the Lower Pliocene, reaching its most northerly distribution in the Middle Pliocene. By 6.5 m.y. ago, as is indicated by the Petaluma Flora, Q. lakevillensis was also present in the central Coast Range and, at least by this time, had the opportunity to exist in sympatric populations with Q. wislizenoides.

Hence, after an extended period of geographic isolation during which these two species differentiated into their modern forms, they came together by the Middle Pliocene as climatic and physiographic changes favored a convergence of their two respective vegetation types. Since that time, a gradual cooling and at least four major glacial advances and retreats have had a dramatic affect on the evolution of California's flora (Raven and Axelrod 1978) and, undoubtedly as well, on the opportunity for sucessful establishment of hybrids between these two live oaks.

DISCUSSION

This limited survey suggests that a substantial amount of hybridization has occurred between Q. agrifolia and Q. wislizenii, particularly in their northern sympatric range where approximately 65 percent of the individuals which were sampled from populations north of San Francisco Bay demonstrated some degree of hybridity. Muller (1952) proposed that speciation in Quercus is primarily a function of geographic isolation, paleoecology, contemporary ecology (accompanied by convergence) and hybridization. The evolutionary analysis described above follows this pattern and suggests that the underlying cause for the north/south hybridization gradient relates to the interaction of two ecologically dissimilar species capable of exchanging genes which came into contact at least 5 m.y. ago and which, in a region of mutual stress at range extremes, produced hybrid derivatives more highly adapted to habitats created by the vicissitudes of the recent Pleistocene than either of the parent species. Muller (1952) and Tucker (1952) also reached similar conclusions in studies involving hybridization in Quercus, and Nobs (1963) cites fossil evidence which suggests that a similar convergence of maritime and continental species of Ceanothus during the Middle Pliocene in the same geographic region, the north central Coast Ranges, resulted in an explosion of speciation in that genus.

This interpretation may account for the surprising percentage of hybrids found in the allopatric populations at Hamilton Base and Lake Co. An alternative explanation, however, relates to one of the drawbacks to this study - i.e., the fact that a third member of the black oak subgenus in California, Q. kelloggii Newb., was not considered in the hybridization analysis. Q. kelloggii is a deciduous oak of northern affinities with deeply lobed leaves which, because of its distinctiveness in contrast to the two evergreen black oaks, was soon recognized as a hybridizing parent in crosses with both Q. wislizenii (Q. X morehus Kell.) and Q. agrifolia (Q. X chaseii McMinn). Although this species was not observed at the Lake Co. site, there are several individuals in the Hamilton Base vicinity. Therefore, this species may have influenced the results from that locality as well as elsewhere by contributing genes to the individuals sampled.

Another drawback to this study was our inability to utilize fruiting characteristics because of the extremely poor acorn set in the populations sampled, possibly due to the two year drought preceding the study. Q. agrifolia is unique amongst all other black oaks in its ability to set mature acorns in one year, whereas the remainder of black oaks require two years, and consideration of this character would undoubtedly have helped in recognizing hybrids.

Jensen and Eshbaugh (1976) demonstrated the value of computerized cluster and principal component analysis in distinguishing the interrelations between three sympatric species of black oaks in the eastern U.S. and they were critical of studies in which all possible putative parents are not considered for the chief reason, as suggested above, that such studies preclude an evaluation of the impact of potential contributors to the gene systems of the individuals sampled. This computerized approach requires a large number of characters in order to be accurate and, if acorn characteristics and the distinctive features of Q. kelloggii were included, it is likely that the Jensen and Eshbaugh techniques could be successfully applied to a study of the precise relationships between the three California black oaks and such a study could conceivably be of great value in clarifying these relationships.

In the absence of such a study, however, the evidence of hybridization between Q. agrifolia and Q. wislizenii will presumably continue to accumulate and the question of according taxonomic status to their recognizable progeny must ultimately be considered. The chief argument in favor of such recognition is that the taxonomic identity is incorporated into regional floras and, thus, communicates the existence of recognizable hybrids to the greatest number of field observers. Perhaps the best argument against this alternative is that it may be literally impossible to provide an adequate description of a type hybrid and the attempt might actually create more confusion than vice versa. In any case, it is reasonably clear that further attention should be devoted to this subject.

ACKNOWLEDGEMENT

Without the inspiration and dedication of Dr. G. L. Stebbins, this paper would not have been possible, and I would also like to thank Dr. Axelrod and Dr. Schorn for their contributions to the evolutionary analysis and Drs. J. R. Griffin and J. R. Sweeney for constructive comments regarding this presentation. The following graduate students at S.F. State were also instrumental in accomplishing this study: C. Bern, H. Chapot, K. Culligan, M. Elliott, E. Gerry, M. Hewlett, P. Sheldon, and D. Showers.

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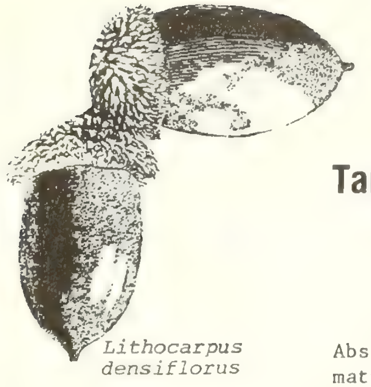
Lithocarpus densiflorus

Tanoak (*Lithocarpus densiflorus*) Leaf Surface Characteristics[1]

M.G. King and S.R. Radosevich[2]

Abstract: Abaxial (lower) and adaxial (upper) surfaces of mature and immature tanoak leaves were characterized. Three types of trichomes (stellate, glandular, and uniseriate) are found on each surface of both mature and immature leaves. Tanoak leaves have stomata only on lower surfaces and the stomatal complex lacks distinct subsidiary cells. Stomata morphology, wax ultrasturcture and cuticular membrane morphology are described.

INTRODUCTION

Tanoak (Lithocarpus densiflorus (H. & A.) Rehd.) is a hardwood, evergreen tree species. It attains a height of 65 to 130 ft. (20 to 40 m) but often occurs in a large shrub-like form as a result of sprouting (usually after fire or other disturbance) and subsequent growth of the dominant stems. It ranges from southwestern Oregon to Santa Barbara, California. Tanoak also occurs in the northern Sierra Nevada, principally between the Feather and American rivers (Fowells, 1965). In the Coast Ranges of California, tanoak is the most abundant hardwood present in timber stands. In Mendocino and Sonoma counties an estimated 169,000 ha (27 percent of the total commercial forest land) is occupied by tanoak (Oswald, 1972). Most (97 percent) of the hardwood type is on land capable of producing conifers (Oswald, 1972).

McDonald (1977) has described the potential economic uses of tanoak. However, in many areas tanoak is considered a problem weed tree. Tanoak can completely dominate a site after logging or fire. Vigorous sprouting, prolific seed production, and rapid early seedling growth enable tanoak to successfully compete with conifers such as Douglas-fir and redwood. Removing hardwood tree competition results in substantial increases in conifer stem enlargement (Radosevich et al., 1976). On heavily infested sites, tanoak control is considered necessary prior to establishing conifers.

Foliar herbicide applications are often limited in effectiveness on old tanoak growth, possibly because of poor absorption through the foliage. Leaf surface features influence wetting, retention, and absorption of foliar applied chemicals (Hull, 1970). King and Radosevich (1979) found that enhanced absorption of ^{14}C-triclopyr (a promising brush control herbicide) was associated with greater stomata densities, lesser amounts of surface wax, greater stellate trichome densities and thinner, more permeable cuticular membranes.

A knowledge of leaf surface characteristics has potential uses for taxonomic studies. Some leaf surface structures can be considered as adaptive plant responses to the environment. In this paper, we describe thoroughly both adaxial and abaxial surfaces of mature and immature tanoak leaves.

MATERIALS AND METHODS

Plant Material

Tanoak acorns were collected in the North Coast Range, Mendocino County, California. After germination, the seedlings were grown in a lath house. To maintain active growth during the winter, all plants were moved to a controlled environment growth chamber. Leaf material was collected near Laytonville, California, and at the Blodgett Forest Research

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[1] Presented at the Symposium on the Ecology, Managment, and Utilization of California Oaks, Pomona, CA. June 25-27, 1979.

[2] Res. Asst. and Assoc. Prof., Dept. of Botany, Univ. of California, Davis, CA 95616.

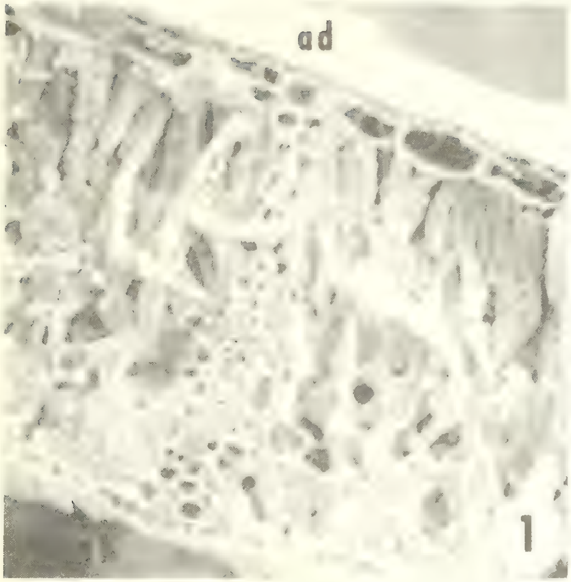

Figure 1. Scanning electron micrograph (SEM) of a cross section of a mature tanoak leaf (Blodgett), critical point dried, gold-coated. Adaxial surface (ad), and abaxial surface (ab). X300.

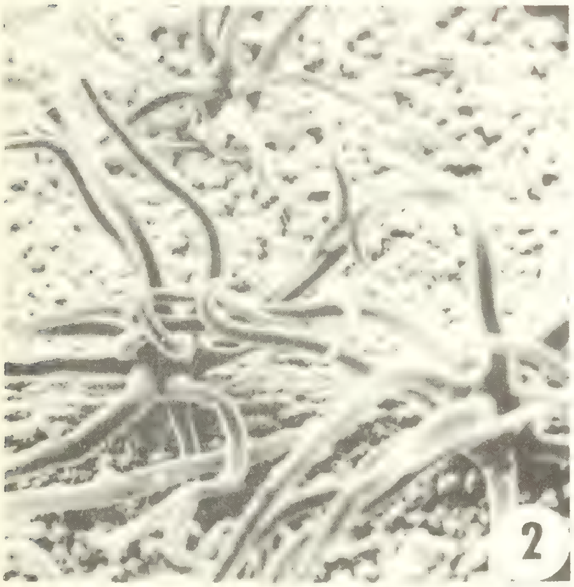

Figure 2. SEM of asymetrically-shaped stellate trichomes on the abaxial surface of a mature tanoak leaf (Laytonville), oven-dried, gold-coated. X230.

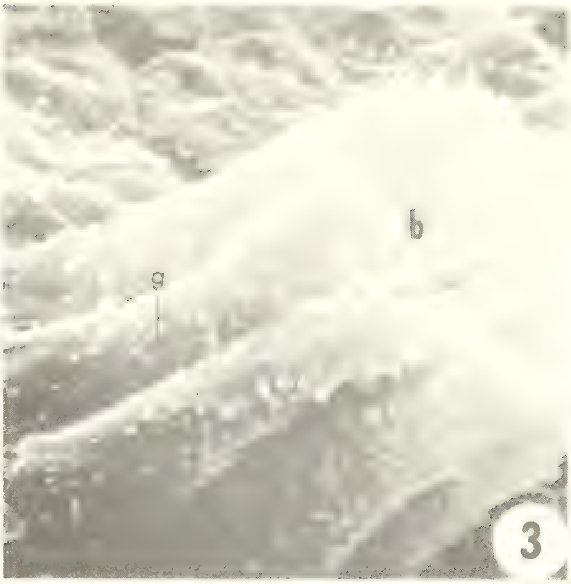

Figure 3. SEM of a base of stellate trichome on the adaxial surface of an immature tanoak leaf (growth chamber), gold-coated, critical point dried. Wax globules (g). X2480.

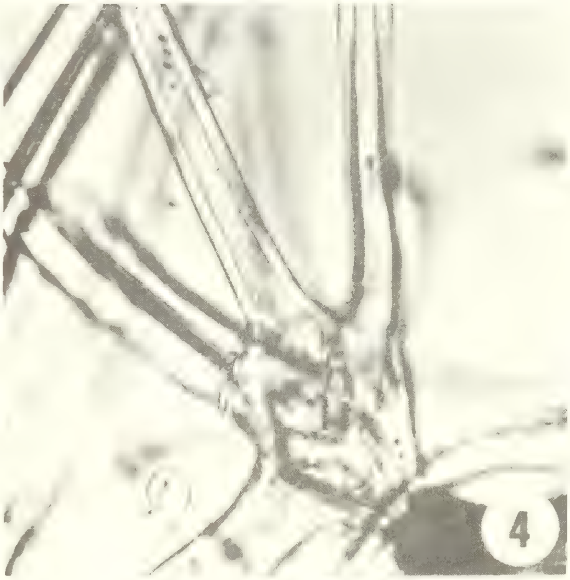

Figure 4. Light micrograph of a stellate trichome (lt). X310.

Station near Georgetown, California. The methods used to store and preserve both growth chamber and field collected material have been described by King (1978).

In all studies mature leaves were a dark green color, glabrate, fully expanded and averaged 2.4 in. (6.0 cm) in length. Immature leaves were a pale green color, densely pubescent, averaged .8 in (2.0 cm) in length and were neither fully expanded nor hardened.

Surface Investigation

The methods used for determining epicuticular wax quantities and ultrastructure, stomata densities, trichome types and distribution and cuticular membrane thickness and morphology have been described (King, 1978; King and Radosevich, 1979). Epidermal anatomy and stomatal morphology were investigated by viewing leaf cross sections under a scanning electron microscope (SEM). Cross sections were cut free-hand from fresh leaves from growth chamber grown plants. They were fixed in FAA (Sass, 1958), dehydrated in a graded ethanol series (50 to 100%), transferred to amyl acetate, critical point dried (Anderson, 1951), and gold-coated. Viability of the cells comprising the various trichome types was determined by staining fresh leaf cross sections with fluorescein diacetate (Widholm, 1972). Cells which were viable fluoresced a bright yellow-green color. Embedded waxes in the cuticular membrane were observed using the polarized light microscopic technique of Norris and Bukovac (1968).

RESULTS AND DISCUSSION

Epidermis

An SEM micrograph of a mature tanoak leaf cross section is shown in figure 1. The upper epidermis is composed of two cell layers. The upper of these is composed of small rectangular shaped cells (in cross section) which are thick walled (see fig. 11 also). The lower cell layer is composed of much larger cells which also have thick walls. Abaxial epidermal cells have rounded outer periclinal cell walls which give the abaxial leaf surface a more undulating aspect than the adaxial surface.

Trichomes

Immature tanoak leaves are densely pubescent on both surfaces. Mature leaves are tough, leathery and nearly glabrous. Three distinct trichome types (stellate, glandular, and uniseriate simple) are found on both surfaces of tanoak leaves, regardless of age. In figures 2 and 4, the asymetrical stellate trichome is shown. Many specialized epidermal cells form a base upon which the stellate trichome sits (fig. 3). The arms of this trichome are thick walled and have no septa (fig. 4). Stellate trichome density is significantly greater on immature than mature leaves and on abaxial rather than adaxial surfaces (table 1). Neither cellular contents nor cytoplasmic streaming were observed in cells comprising stellate trichomes. None of the component cells gave a positive reaction (fluoresced) to fluorescein diacetate even on the youngest leaves observed.

Table 1. Surface characteristics of tanoak leaves.[1]

Leaf Age	Leaf Surface	Stomata[2] (No./mm^2)	Trichomes[3] (No./mm^2)	Cuticular Membrane Thickness[3] (um)
Immature	Abaxial	890	54.9a	1.2a
	Adaxial	---	33.5b	1.0a
Mature	Abaxial	555	12.1c	3.7b
	Adaxial	---	2.1d	4.4c

[1] Taken from King and Radosevich (1979).

[2] Means differ significantly at $t_{.05}$.

[3] Means followed by the same letter do not differ significantly at the 5% level, Duncan's Multiple Range test.

Figure 5 shows the glandular trichome found on tanoak leaf surfaces. Glandular trichomes are more abundant on immature than mature leaves and on abaxial rather than adaxial surfaces. This type of trichome has a multicellular (more than eight cells), globose head on a uniseriate stalk composed of 3 to 4 cells. The cells comprising the head often contain a dense, red-brown material. One or more viable cells were found about 30 percent of the time in the glandular trichomes.

The simple, uniseriate trichome (fig. 6, 7a) is composed of 3 to 4 cells, is derived from a single epidermal cell, and frequently is bent horizontally on the leaf surface. The basal or apical cells of the uniseriate trichome fluoresced 56 percent of the time but seldom did all the component cells.

Little is known about the uniseriate and glandular trichome types. However, stellate trichomes may have many physiological functions (Uphof, 1962). Initially they may hold

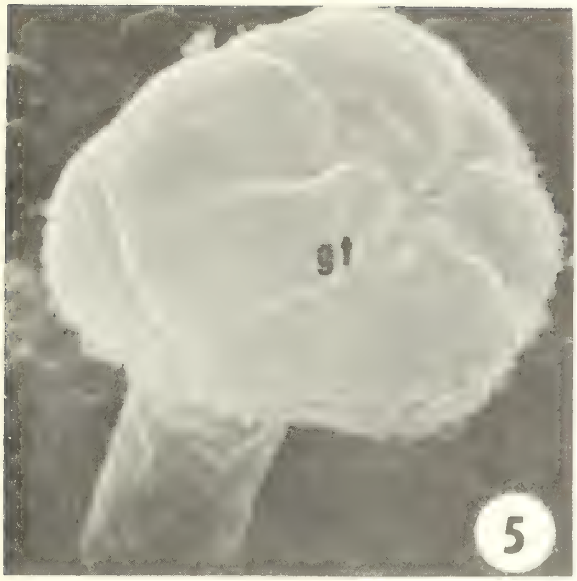

Figure 5. SEM of a glandular trichome (gt). Leaf was critical point dried, gold-coated. X1410.

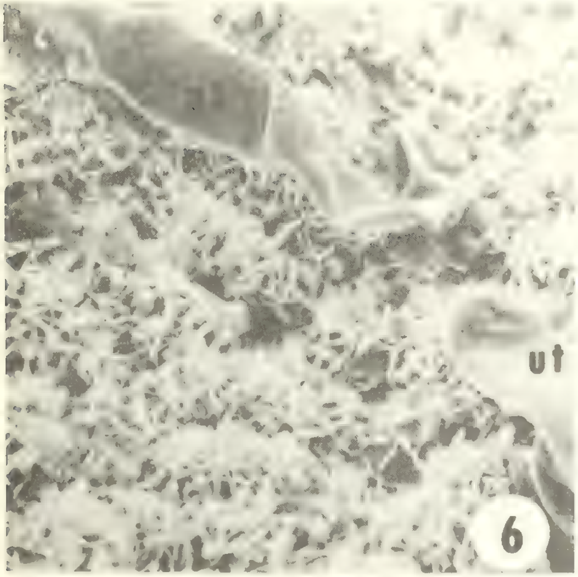

Figure 6. SEM of uniseriate trichomes, platelet wax on the abaxial surface of tanoak leaves (Blodgett), oven-dried, gold-coated. Uniseriate trichome (ut). X1150.

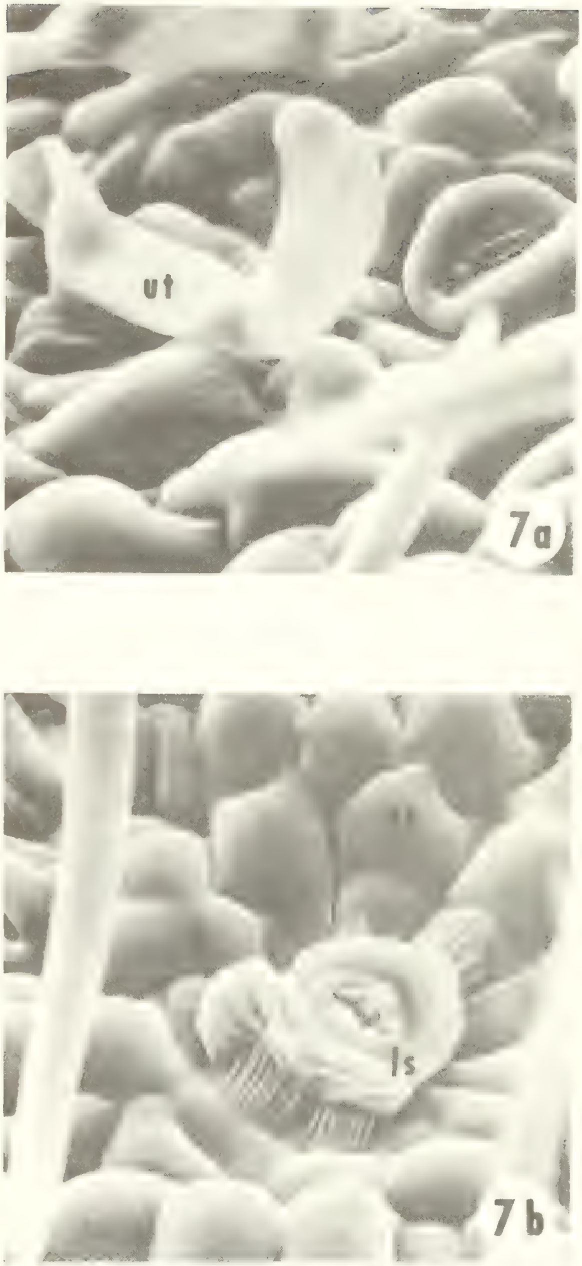

Figure 7. SEM of the abaxial surface (wax removed) of mature tanoak leaves (Blodgett). a) Oven-dried leaf, gold-coated. Uniseriate trichome (ut), normal stomata (s). X1260. b) Oven-dried leaf, gold-coated. Large stomata (ls), cuticular membrane surface (cs). X1164.

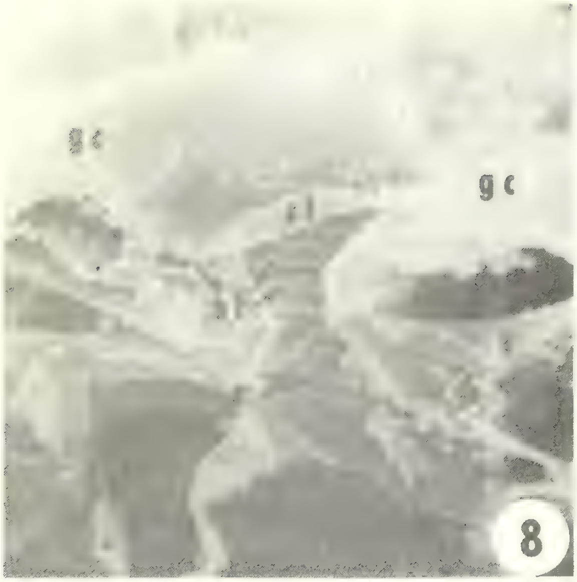

Figure 8. SEM of a cross section of a stomata on a mature tanoak leaf (Blodgett), critical point dried, gold-coated. Guard cells (gc), cuticular ledge (cl) and baffles (bf). X5020.

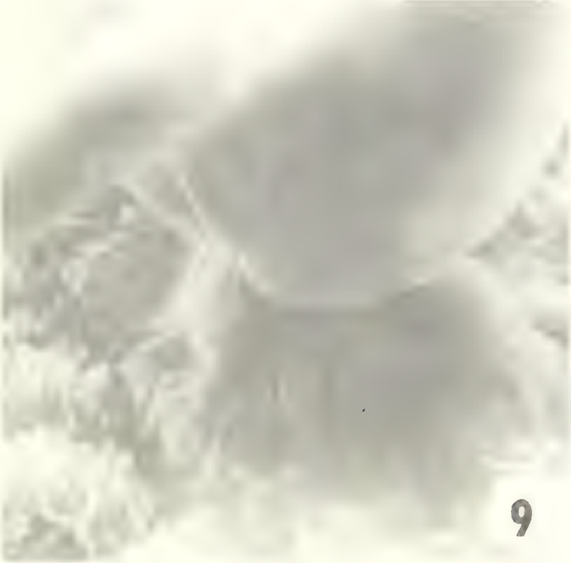

Figure 9. SEM of the abaxial surface of a mature tanoak leaf (Laytonville) showing attachment of the stellate trichome (lt) to its base (b). X1450.

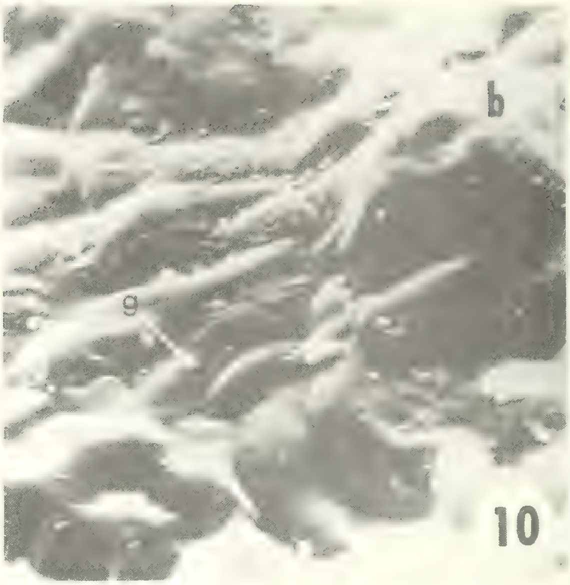

Figure 10. SEM of the adaxial surface of a mature tanoak leaf (Blodgett). Oven dried, gold-coated. Wax globules (g), base of stellate trichome (b). X780.

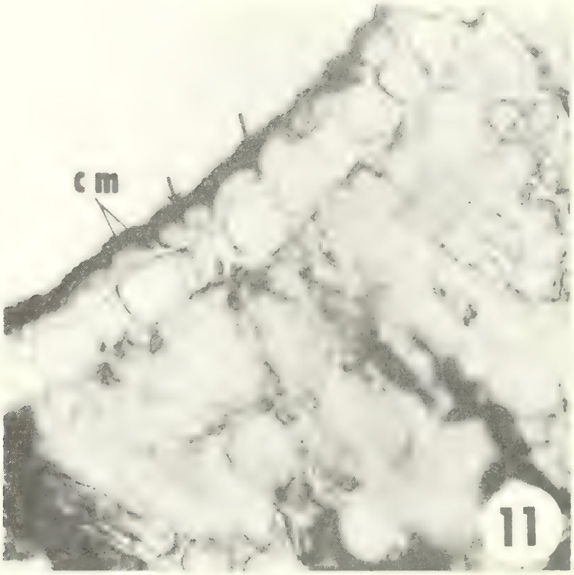

Figure 11. Light micrograph of a fresh, free-hand, cross section of the adaxial surface of a mature tanoak leaf (growth chamber), stained with a mixture of Sudan III and Sudan IV. Cuticular membrane (cm). Note cuticular pegs or flanges (arrows). X390.

the developing leaves together in the bud. After bud-break, they can protect the young leaves from dessication by increasing the vapor boundary layer thickness. A dense stellate trichome covering might also reduce the amount of insolation and help keep leaf temperatures from becoming excessive (Uphof, 1962).

Stomata

Tanoak leaves have no stomata on adaxial surfaces. Stomata are more dense on abaxial surfaces of immature than mature leaves (table 1). The stomatal complex has no distinct subsidiary cell (fig. 7a), which agrees with earlier descriptions of this species (Camus, 1954). Occasionally stomata which are morphologically different (fig. 7b) from the normal type (fig. 7a) were encountered on lower surfaces of mature and immature leaves. The guard cells of the "large" type (fig. 7b) have a convoluted surface aspect and the cuticular membrane surface of the surrounding epidermal cells is somewhat striated. Guard cells of the "normal" type have an unusual pear-shaped appearance in cross section. Baffles on the interior of the pore surface (fig. 8) and a cuticular ledge over the upper portion of the pore were observed. Both of these features reduce the effective pore diameter and increase diffusive resistance which may aid in water conservation.

Cuticle

Tanoak leaves are heavily waxed in comparison to many herbaceous species. Much greater amounts of wax were found on mature (200 ug/cm^{2}) than immature (82 ug/cm^{2}) tanoak leaves (King and Radosevich, 1979). The dried extracted waxes are a pale yellow-brown and are sometimes translucent. Wax ultrastructure on tanoak leaves has been previously described (King and Radosevich, 1979). Long thin wax ridges are found on the abaxial surfaces of immature tanoak leaves but cover little of the total surface area. Wax globules are scattered randomly over the adaxial surfaces of immature leaves (fig. 3). Dense formations of wax platelets superimposed on an amorphous wax sheet are found on the abaxial surfaces of mature leaves (fig. 6,9). However, wax platelets are seldom observed on stellate trichome bases on the abaxial surfaces of mature leaves (fig. 9). No platelets or wax ridges were seen on the adaxial surfaces of tanoak leaves regardless of age. A thick, amorphous sheet of wax completely covers the adaxial surfaces of mature leaves (fig. 10).

The cuticular membrane is significantly thicker on mature than immature tanoak leaves (table 1). A polarized light technique (Norris and Bukovac, 1968) indicated that embedded waxes are present in both adaxial and abaxial cuticular membranes of mature leaves. Extensions of the cuticular membrane over the anticlinal adaxial epidermal cell walls were noted on mature leaves (fig. 11).

SUMMARY

Tanoak leaves undergo marked changes as they mature. The stellate trichome density on mature leaves is 16 percent of that present on immature leaves (King, 1978). The frequency of the glandular and uniseriate trichome types also declines with age. Stomata density on mature leaves is 62 percent of that on immature leaves. Epicuticular wax quantities increase with age and the wax ultrastructure changes markedly on both surfaces. Mature leaves have a thicker, less permeable cuticular membrane than immature leaves.

Stellate trichomes on tanoak leaf surfaces may provide mechanical protection to young, developing leaves. By increasing the vapor boundary layer (thus increasing diffusive resistance) they may protect the leaf from excessive water loss. Dense formations of stellate trichomes decrease the amount of insolation, aid in maintaining optimal leaf temperatures, and provide physical protection against damage. Cuticular ledges over stomatal pores and baffles lining the pore may also aid in water conservation. Mature tanoak leaves are heavily waxed and have relatively thick cuticular membranes which can decrease the rate of water loss and provide mechanical protection against disease and physical abrasion.

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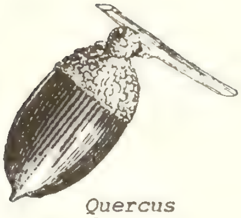
Quercus dumosa

Adaptations of Mediterranean-Climate Oaks to Environmental Stress[1]

Philip W. Rundel[2]

Abstract: Plant growth-form and leaf duration are structural traits which provide important adaptations of oaks to individual environments. Shrubby taxa of oaks dominate in areas with relatively severe environmental stresses of drought, short growing season, or nutrient deficiency. Water stress is a primary determinant of leaf duration in oaks.

INTRODUCTION

Species adaptations to gradients of environmental stress may take many forms in the oaks. The most significant environmental gradient in California is aridity, brought on by a mediterranean climate. During the winter when precipitation is present, mean temperatures are too low to allow favorable photosynthetic activity. When temperatures are favorable for growth during the summer months, precipitation is absent. For oaks, as well as for other elements of our flora today, the present assemblage of species represents the outcome of evolutionary selection of genotypes adapted to these climatic stresses.

In addition to aridity, mediterranean-climate conditions also promote a tendency toward frequent fire. Groups of adaptive characteristics have clearly evolved in many California oaks to promote species survival, particularly in chaparral and forest environments where fires are frequent.

With the existing degree of topographic diversity in California, significant temperature gradients are present. Both mean growing season temperatures as well as length of growing season vary along these gradients, providing a broad range of environmental conditions for selection to respond to. Since higher mean temperatures in California are generally correlated with lower annual precipitation, these two factors are interrelated.

A final major environmental stress influencing the evolution of oaks in California has been nutrient availability. The complex geological history of many parts of the state has produced mosaics of soil types which can again act as selective factors in the evolution of a variety of taxa including oaks. Since nutrient cycling in oaks is the subject of a specific review in this volume, it will not be considered here.

ADAPTATIONAL STRATEGIES

In looking at broad evolutionary patterns in oaks, two groups of structural traits can be recognized which have a great deal of significance in the adaptation of individual species to their environments. These traits are the plant growth form, whether a shrub or tree, and the leaf duration, whether evergreen or deciduous. The growth form which a plant takes is a function of the relative allocation of carbohydrates synthesized through photosynthesis to each of four compartments (fig. 1). For trees a very large part of this allocation goes to support tissues such as a trunk and branches to give a plant a large size. Height in plants may be selected for to outcompete plants shorter in stature, to avoid ground dwelling predators, to reach sunlight at the top of a forest canopy, or to evade light surface fires. In shrubs a main trunk is usually absent and much less

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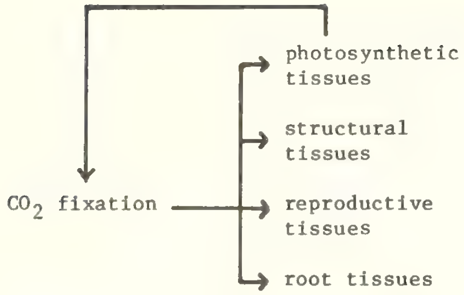

Figure 1--The pattern of carbon allocation to plant tissues.

relative allocation to support tissues is required. Root tissues in most shrub species are a very significant part of the total biomass and in some environments may be much greater in biomass than above-ground tissues. In general, shrubby growth and associated high root-to-shoot ratios are associated with conditions of high environmental stress. Common forms of stress which may promote dominance of shrub species are arid conditions, high fire frequency, cold temperatures with a short growing season, low nutrient availability, and heavy grazing. Finally, herbaceous species, not represented in the oaks, are characterized by allocating high proportions of their carbohydrates to photosynthetic and reproductive tissues. Minimal structural support and relatively small root biomasses are commonly present. In annual plants 15-30 percent of annual production may go to reproduction alone.

Selective pressures for evergreen or deciduous characteristics are a response to the seasonality of the environment. When a predictable drought or cold period is present in an environment so that no photosynthetic production can take place during a particular season, then natural selection should promote deciduous leaves if the metabolic costs of maintaining leaves during the stress period is greater than the cost of producing new leaves the following season. Where stress periods are variable in length and intensity so that favorable conditions for photosynthetic production may occur at any time during the year, evergreen leaves have the advantage of always being present to utilize such favorable conditions during normal stress periods. Since evergreen leaves commonly remain for two years or more, the metabolic expense of producing them maybe much less than for deciduous leaves. Other advantages of evergreen leaves accrue in nutrient-poor environments for several reasons. Long leaf duration allows greater net photosynthetic production per unit of leaf nutrient and thus a more efficient use of these nutrients. In addition, evergreen leaves are able to store nutrients during the winter for later growth, and further drop their old leaves slowly to allow a better return of nutrients to the soil through decomposition. Despite these advantages, evergreen leaves have the significant disadvantage of having a relatively low rate of maximum photosynthesis in comparison to thinner deciduous leaves.

In California the 15 species of native oaks can be arrayed into community types where they predominately occur for each of four growth categories (table 1). Montane forests contain all four types, but individual habitats commonly contain only a single species. Foothill woodland communities generally lack shrubby oaks, but both deciduous and evergreen trees are present. Chaparral and desert habitats usually support only a single growth-form of evergreen shrubs. This distribution pattern of growth-forms of oaks in California is very similar to that of the Mediterranean region of France where deciduous tree, evergreen tree, and evergreen shrub forms of oak are all present.

The adaptive significance of individual growth-forms of oak, as discussed below, can be seen in the differing ecological responses of shrubs and trees and of evergreen and deciduous-leaved plants. The diversification of California oaks into individual growth-forms clearly does not follow taxonomic lineages. The three species of black oaks in California include both deciduous (Q. kelloggii) and evergreen trees (Q. wislizenii and Q. agrifolia). Among the white oaks all four growth-forms are present. The closely related Quercus chrysolepis group includes this evergreen tree as well as three evergreen shrubs, Q. dunnii, Q. vaccinifolia and Q. cedroensis of Baja California. Quercus salderiana, an evergreen shrub in the northern part of the state, is most closely related to deciduous tree oaks of the eastern United States. Quercus garrayana may occur in its typical deciduous tree form or in taxonomically distinctive shrub forms. A similar pattern of change may occur in Q. wislizenii, normally an evergreen tree.

BIOMASS ALLOCATION

Patterns of biomass allocation in oaks differ considerably with shrub and tree growth-forms. Since shrubs typically lack a central trunk and have much smaller structural requirements for woody tissue than trees, it is not surprising to find that shrubs allocate a greater proportion of their above-ground biomass to leaves than do trees. Examples of literature

Table 1--Distribution of California oaks by community distribution and growth-form

Community	Growth Form			
	deciduous tree	deciduous tree	evergreen tree	evergreen shrub
montane forest	*Q. kelloggii*	*Q. garrayana* var. *breweri*	*Q. chrysolepis*	*Q. vaccinifolia*
				Q. salderiana
foothill woodland	*Q. garrayana*		*Q. wislizenii*	
	Q. lobata		*Q. agrifolia*	
	Q. engelmanii			
	Q. douglasii			
chaparral		*Q. garrayana* var. *breweri*		*Q. dumosa*
				Q. durata
				Q. dunnii
				Q. wislizenii var. *frutescens*
desert				*Q. turbinella*
island endemic			*Q. tomentella*	

data on those relative allocation patterns are shown for a series of oaks in table 2, using the four major categories of leaf duration and growth-form previously described. For evergreen and deciduous shrubs the range of relative leaf biomass ranges from 10-17 percent of above-ground biomass, while values for evergreen and deciduous trees range from 2-7 percent. For most shrubs species the remaining biomass is completely allocated to branch tissues, although a significant trunk may form in *Q. ilicifolia*, an eastern scrub oak.

SHOOT AND ROOT CHARACTERISTICS

Comparative data on the ratio of root biomass to above-ground biomass (root-shoot ratios) in shrubby and tree oaks also show a fundamental difference in patterns of biomass allocation (table 2). Root-shoot ratios for four species of trees range from 0.18 to 0.91, indicating a large dry weight of shoot biomass. In shrubby species, however, root biomass far exceeds that of shoots with root shoot ratios of 3.17 to 6.28. Much of the relatively large proportion of root biomass is concentrated in a massive woody root crown which allows efficient resprouting following fires (Muller, 1951; Plumb, 1961, 1963). Most tree oaks sprout principally in an epicormic manner from above-ground tissue following fires, but some deciduous tree oaks such as *Q. douglasii* and *Q. lobata* may sprout poorly or not at all.

With repeated fires this root crown gradually enlarges and the number of resprouted stems present increases (Pond and Cable, 1960). The storage of energy reserves and possibly nutrients and water in the root crown makes continued resprouting possible. Even without the root crown biomass, it appears that the root-shoot ratio of shrub oaks is still significantly greater than that of tree oaks. Calculations of root-shoot ratio in *Quercus turbinella* ignoring root crown biomass still give a value of 1.9 (Davis, 1978).

For obvious reasons detailed studies of root distribution in oaks are relatively few. Early observations noting the correlation of *Quercus lobata* in California with deep alluvial soils suggested that this species has deep and well-developed root system reaching the water table (Jepson, 1910; Cannon, 1914). These same studies suggested that *Q. douglasii* was associated with shallow soils on exposed hillsides and thus root access to the water table was unlikely. Cannon (1914) hypothesized that *Q. agrifolia* has no deep roots, but instead developed an extensive shallow root system. *Quercus kelloggii* may have a single major tap root or numerous major vertical roots depending on its substrate.

Lewis and Burghy (1964, 1966) used tritiated water to obtain the first quantitative data on rooting depths in California tree oaks.

Their studies in the foothills of the Sierra Nevada indicate that Q. lobata, Q. douglasii and Q. wislizenii may all root to depths of 10-20 m under favorable conditions. On one of their plots they found Q. douglasii tapping water at 26 m depth. Studies of seasonal water stress patterns of three species of Quercus in the Santa Lucia Mountains of Monterey County indicate that both Q. lobata and Q. agrifolia have root systems which reach ground water, while Q. douglasii roots do not (Griffin, 1973). The only eastern deciduous oak for which good data are available, Q. macrocarpa, has a deep and ramifying root system with a tap root reaching 4 m depth and more than 30 large branch roots extending outward 6-20 m (Weaver and Kramer, 1932).

Shrubby evergreen oaks in Southern California and Arizona have surprisingly deep root systems. Hellmers et al. (1955) reported roots of Q. dumosa in the San Gabriel Mountains at a depth of nearly 9 m, the deepest of any of the chaparral plants they observed. They noted few feeder roots in the top 15 cm of soil. More detailed excavations of Q. turbinella in Arizona chaparral found a tap root penetrating through cracks and fissures to bedrock at a depth of nearly 7 m (Davis, 1978; Saunier and Wagle, 1967). Even at this depth individual roots still reached 5 mm diameter. A dense mat of fine surface roots, most less than 2 mm diameter, extend out radially from the center of the shrub through the upper 30 cm of soil. Major laterals are joined beneath the canopy to a massive woody root crown similar to those characteristic of many chaparral shrubs which resprout following fire.

LEAF CHARACTERISTICS

Evergreen and deciduous leaves of oaks, as with other plant groups, have differences in leaf characteristics which influence their physiological behavior. Evergreen leaves in temperate latitudes are characteristically sclerophyllous in texture with a relatively thick and leathery feel. These leaves typically remain on oaks for two growing seasons but occasionally longer. Deciduous leaves which are much thinner and less leathery in texture are much less resistant to environmental extremes and are present on the shrubs only during favorable growing periods.

The greater sclerophylly of evergreen oak leaves can be seen in data on leaf specific weight shown in table 3. Evergreen shrubs and trees have values from 12-18 g cm^{-2} while deciduous trees range from 7-10 g cm^{-2}. One species of deciduous shrub, Q. ilicifolia from arid sandy habitats on the East Coast, has an intermediate value which is quite high for a deciduous leaf.

Table 2--Above-ground biomass and relative allocation of biomass in the genus Quercus. Data from Mooney et al., 1977; Whittaker and Woodwell, 1963; Lossaint, 1973; Whittaker and Niering, 1975; Whittaker, 1966; Johnson and Risser, 1974; Duvigneaud and Denaeyer-De Smet, 1970; Davis, 1978.

	location	Above-ground biomass	Biomass Distribution				
			leaves	branches	trunk	reproductive tissues	root-shoot ratio
		($g\ m^{-2}$)	percent				
Evergreen shrubs							
Q. dumosa	California	2046	17.1	82.9	-	-	
Q. agrifolia	California	4607	10.0	90.9	-	-	
Q. coccifera	France	2350	17.0	83.0	-	-	4.17
Q. turbinella	Arizona	1811	-	-	-	-	3.17
Deciduous shrubs							
Q. ilicifolia	New York		16.5	31.4	52.1	-	6.28
Evergreen trees							
Q. ilex	France	26900	2.6	10.0	87.4	-	0.18
Q. hypoleucoides	Arizona		12.5[1/]	24.3	63.3	-	
Deciduous trees							
Q. coccinea	New York		7.5	27.5	64.8	0.2	0.47
Q. alba	New York		6.9	21.2	71.4	0.5	0.91
			1.7	27.3	71.0	0.02	
Q. stellata	Oklahoma	14217	2.4	38.9	58.7	-	
Q. marilandica	Oklahoma	3556	3.6	27.1	73.2	-	
Q. robur	Belgium	4290	2.4	32.2	65.4	-	

[1/] current twigs and leaves included

Table 3--Comparative leaf characteristics in the genus Quercus. Sclerophyll index is calculated as (percent lignin and cellulose x 100)/crude protein content. Data from Mooney et al, 1977; Lossaint, 1973; Whittaker and Woodwell, 1968; Whittaker, 1966; Johnson and Risser, 1974; Duvigneaud and Denaeyer-De Smet, 1970; Cromack and Mark, 1977; Loveless, 1962.

	location	specific weight	nitrogen	cellulose	lignin	crude fiber	sclerophyll index
		(mg cm^{-2})	percent	percent	percent	percent	
Evergreen shrub							
Q. dumosa	California	14.0	1.30	18.2	11.7	29.9	236
Q. coccifera	France		1.74	18.1	10.3	28.4	261
Q. chapmanii	Florida	12.0	1.97	21.8	13.2	35.0	284
Q. myrtifolia	Florida	13.4	1.77	25.3	13.0	38.3	346
Q. breviloba	Texas					25.2	261
Evergreen trees							
Q. agrifolia	California	13.0	1.15	20.4	10.5	30.9	275
Q. virginiana	Florida	17.0	1.67	32.6	14.4	47.0	450
	Texas					28.7	268
Q. wislizenii	California	13.8					
Q. chrysolepis	California	18.5					
Deciduous shrubs							
Q. ilicifolia	New York	13.4	1.40				
Deciduous trees							
Q. douglasii	California					13.6	69
Q. coccinea	New York	9.8	0.79				
Q. alba	New York	8.3	0.79				
	Tennessee	9.2	1.40				
Q. pubescens	France	7.0					
Q. kelloggii	California	9.2					
Q. stellata	Oklahoma		4.10				
Q. marilandica	Oklahoma						
Q. robur	Belgium		2.4				
Q. prinus	S.E. U.S.		2.0	20.2	12.6	32.8	168
Q. coccinea	S.E. U.S.		1.8	15.5	15.5	31.0	177
Q. prinus	S.E. U.S.		2.0	14.9	9.1	26.0	132

Another measure of the comparative sclerophylly of evergreen and deciduous oak leaves is the sclerophyll index (table 3). This index is the ratio of crude fiber content (cellulose and lignin) to crude protein content for a leaf (Loveless 1961, 1962). Evergreen shrubs and trees have sclerophyll indices of 236-450, values typical of evergreen chaparral shrubs. Values for deciduous trees range from 69-177. A comparison of the individual components of this sclerophyll index (table 3) indicate that nitrogen levels (the major limiting component of proteins) are not significantly different in evergreen and deciduous leaves of oaks, with the exception of the high nitrogen levels reported for *Q. stellata* and *Q. marilandica* in Oklahoma. Among the evergreen shrubs oak leaf nitrogen levels are generally higher than those of other evergreen shrubs in the same habitats, indicating a relatively high nitrogen requirement. The major basis for the high values of sclerophyll index in evergreen species is the high level of both cellulose and lignin in the leaves. Together these structural components comprise 28-47 percent of the leaf dry weight of evergreen species. Less than 14 percent of the dry weight of deciduous leaves of *Q. douglasii* are cellulose and lignin.

PRODUCTIVITY

When productivity of oaks is calculated on the basis of some measure of available photosynthetic tissue, the significance of evergreen and deciduous leaves can be seen. The general pattern expected is that sclerophyllous evergreen leaves with thick cuticles are slow at taking up CO_2 and therefore photosynthesize at much lower maximum rates than deciduous leaves where gas exchange is rapid. Evergreen leaves are present all twelve months of the year, however, and may therefore be able to photosynthesize during favorable conditions when deciduous plants may be leafless.

Net annual above-ground productivity calculated per unit of leaf dry weight varies from 0.85-1.50 g g^{-1} for evergreen shrubs and trees, and from 2.23-3.66 g g^{-1} for deciduous trees (table 4). Deciduous trees, therefore, are much more efficient at utilizing photosynthetic tissues for production. This pattern of relative efficiency between evergreen and deciduous leaves is less apparent on a leaf area basis where evergreen leaves have a productivity of 160-210 g m^{-2}, and deciduous trees have a range of 216-345 g m^{-2}. This more similar pattern of productivity per unit

Table 4--Above-ground net productivity and allocation of new growth in the genus Quercus. Data from Mooney et al., 1977; Whittaker and Woodwell, 1968; Lossaint, 1973; Whittaker and Niering, 1975; Whittaker, 1966; Johnson and Risser, 1974; Duvigneaud and Denaeyer-De Smet, 1970.

	location	above-ground productivity	relative allocation of growth				productivity		
			leaves	branches	trunk	reproductive tissues			
		$(gm^{-2}yr^{-1})$	percent	percent	percent	percent	$(g\ g^{-1}leaf)$	$(g\ m^{-2}leaf)$	$(g\ g^{-1}leaf\ N)$
Evergreen shrubs									
Q. dumosa	California	425	87.4	11.3		1.3	1.50	210	115
Q. agrifolia[1]	California	338	87.6	7.5		4.9	1.23	160	107
Q. coccifera	France	340					0.85		49
Deciduous shrubs									
Q. ilicifolia	New York		6.2	25.8	11.7	0.3	1.61	254	115
Evergreen trees									
Q. ilex	France	675					1.04		73
Q. hypoleucoides	Arizona		47.6[2]	27.9	24.5				
Deciduous trees									
Q. coccinea	New York		43.8	29.6	24.5	2.1	2.23	304	282
Q. alba	New York		44.9	31.1	20.2	3.8	2.24	216	284
	Tennessee		26.6	35.3	37.8	0.3	3.66	345	261
Q. stellata	Oklahoma	874	39.7	36.2	24.0		2.51		61
Q. marilandica	Oklahoma	387	33.3	25.6	41.1		3.00		73
Q. robur	Belgium	282	36.5	40.4	23.0		2.73		113

[1] shrub form
[2] current twigs and leaves included

leaf area is due not to the equal photosynthetic rates of the two leaf forms but rather to the longer period of productivity in evergreen species.

Since nitrogen may be limiting to productivity in many environments, productivity can also be calculated per unit of leaf nitrogen. On this basis evergreen leaves range in productivity from 49-107 $g\ g^{-1}$ leaf nitrogen. Deciduous leaves are much more variable on this basis. Quercus coccinea and Q. alba which have low concentrations of leaf nitrogen have values of 261-284 $g\ g^{-1}$ leaf nitrogen, while the other four deciduous species for which data are available have values almost identical to those of the evergreen species.

Differences in productivity patterns are not restricted to evergreen versus deciduous leaves in oaks, but occur in shrubs versus tree growth-forms as well. As with biomass distribution, the above-ground productivity and relative allocation of new growth in shrub and tree growth-forms of oak differ significantly (table 4). In the two California evergreen shrubs for which data is available, Q. dumosa and Q. agrifolia (shrubby form), over 87 percent of new growth is allocated to leaves. Leaf allocation in the five species of deciduous oak trees for which data are available range from 26-45 percent Quercus ilicifolia, a deciduous shrub, has a intermediate value.

Allocation of net productivity to reproductive structures in oaks appears to be relatively low, although data are limited. Values for six species range from 0.3-4.9 percent (table 4), but careful measurements in years of good acorn production would likely produce greater allocations. Griffin[3] has found that production of viable acorns by Quercus lobata in the Carmel Valley (Monterey County, California) is directly related to total precipitation of the previous growing season (fig. 2).

WATER RELATIONS

In addition to the photosynthetic differences between evergreen and deciduous leaves, the greater sclerophylly of evergreen leaves makes them considerably more drought resistant. Leaves of deciduous oaks are highly sensitive to decreases in leaf water content. Both Quercus pubescens and Q. robur, deciduous trees in central Europe, initiate stomatal

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[3] Unpublished data. James R. Griffin, Univ. of Calif., Hastings Nat. History Reservation, Carmel Valley, Cal.

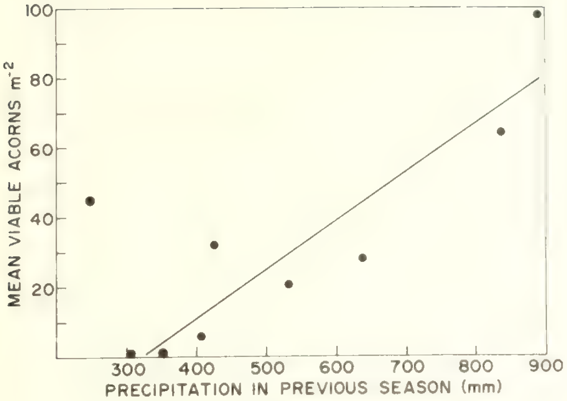

Figure 2--Collection of viable acorns of *Quercus lobata* at ground level in relation to precipitation during the previous growing season at the Hastings Natural History Reservation, Carmel Valley. Unpublished data of James R. Griffin.

closure when relative leaf water content drops to 90 percent of its saturated level (Larcher, 1960; Pisek and Winkler, 1953; Arvidsson, 1951). As leaf relative water content drops below 70%, stomatal closure is complete in *Q. pubescens* and positive net photosynthesis ceases (fig. 3). In *Q. robur*, a more shade-adapted species, stomatal closure occurs more rapidly (Pisek and Winkler, 1953). Because of the thin cuticle of deciduous leaves, cuticular transpiration continues at this stage at a level 30-50 percent of the maximum rate of transpirational water loss with fully open stomata (Pisek and Berger, 1938; Larcher, 1960). As leaf water loss continues, the first symptoms of desiccation injury appear at relative water contents of about 50 percent in *Q. pubescens* (Larcher, 1960).

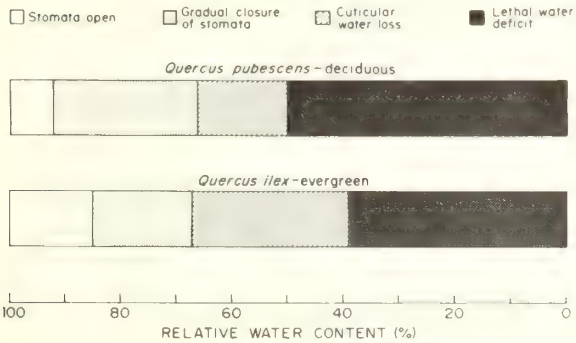

Figure 3--Comparative water relations of *Quercus pubescens* (deciduous) and *Quercus ilex* (evergreen) in the Mediterranean region of Europe. See text for discussion.

In the evergreen *Q. ilex* of the mediterranean region of Europe, stomatal closure does not begin until the leaves reach a relative water content of 85 percent of their saturated level. Stomatal closure is fairly rapid, however, and occurs at a similar relative water content to that of the deciduous oak species. The most signficant difference between the two types of leaves is that cuticular transpiration is negligible (less than 3 percent maximum transpiration rates) in the evergreen leaves because of their thick cuticle. As a result *Q. ilex* is able to limit its transpirational water loss ten times more effectively than the deciduous species by closing its stomata. Furthermore, desiccation injury in *Q. ilex* does not occur until relative water contents of 40 percent are reached.

The characteristic pattern of the replacement of deciduous oaks by evergreen oaks along a gradient of increasing aridity in both California and Europe results to a large part from the physiological characteristics of each leaf type as described above. Both deciduous and evergreen oaks in California may experience midday stomatal closure late in the growing season as water stress increases. Evergreen leaves limit their water loss under drought conditions by rapidly closing their stomata and restricting cuticular transpiration to very low levels. Since the relative water content of evergreen leaves can reach much lower levels without desiccation injury than that of deciduous leaves, they are able to endure much longer drought periods. Experimental studies have indicated that the evergreen *Q. ilex* can endure drought periods 15 times longer than the deciduous *Q. pubescens* (Larcher, 1960).

Few data are available on field measurements of the relative drought tolerance of ecological groups of oaks. Griffin (1973) made intensive studies of water relations of *Quercus douglasii*, *Q. lobata*, and *Q. agrifolia* in the coast ranges of Monterey County over a three year period. The maximum dawn water stress he recorded in mature trees was 40 bars in *Q. douglasii* in late summer. Under stressful conditions, midday water stresses in *Q. douglasii* always exceeded values for *Q. agrifolia* by 5-10 bars, indicating that the latter species was able to tap ground water supplies unavailable to *Q. douglasii*. Bottomland stands of *Quercus lobata* and *Q. agrifolia* showed little difference in maximum stress between very dry and wet years, again

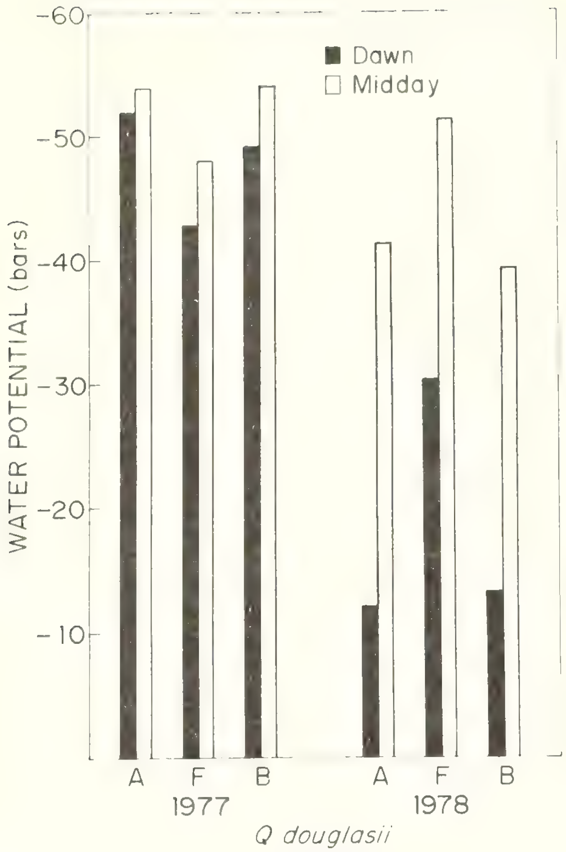

Figure 4--Comparative water potentials of Quercus douglasii at dawn and midday for maximum seasonal stresses of 1977 and 1978 at three sites in the foothill zone of Sequoia National Park, California.

indicating their ability to utilize ground water. In these bottomland stands density of trees is unrelated to water stress. On slopes where Q. douglasii occurs on shallower soils, however, density of trees is strongly related to water stress as water is a limiting resource (Griffin, 1973). Under these conditions denser stands of vegetation on more "mesic" north-facing slopes may actually undergo drought stress earlier than more open stands of vegetation on the "xeric" south-facing slopes.

Field measurements of water stress of Quercus agrifolia in the Puente Hills of Southern California indicated that drought stress never exceeded 20 bars in August of 1972, an unusually dry year (Syvertson, 1974). These stress levels were greater than those reached in adjacent individuals of Juglans californica but less than those in Heteromeles arbutifolia.

In comparison to California oaks, eastern deciduous oaks do not develop extreme water stress. Studies of three species of Quercus in New England indicated maximum summer water stresses of only 25 bars (Federer, 1978).

Recent comparative studies of the water relations of four species of oaks in the foothill zone of Sequoia National Park, California, during the very dry winter of 1977 and the subsequent moist winter of 1978 allow an interpretation of the response of oaks species to environmental drought. Midday water stresses of over 50 bars were present in Q. douglasii and Q. chrysolepis in the fall of 1977, with stresses close to 50 bars also present in Q. wislizenii (fig. 4 and 5). The severe nature of this drought is indicated by the minimal level of recovery from water stress overnight in the lowered dawn readings. Maximum stesses for the same oaks in 1978 were considerably lower in all species (fig. 4 and 5). Dawn levels of water stress were 10-30 bars lower for the four species, indicating considerable overnight recovery of plant water status.

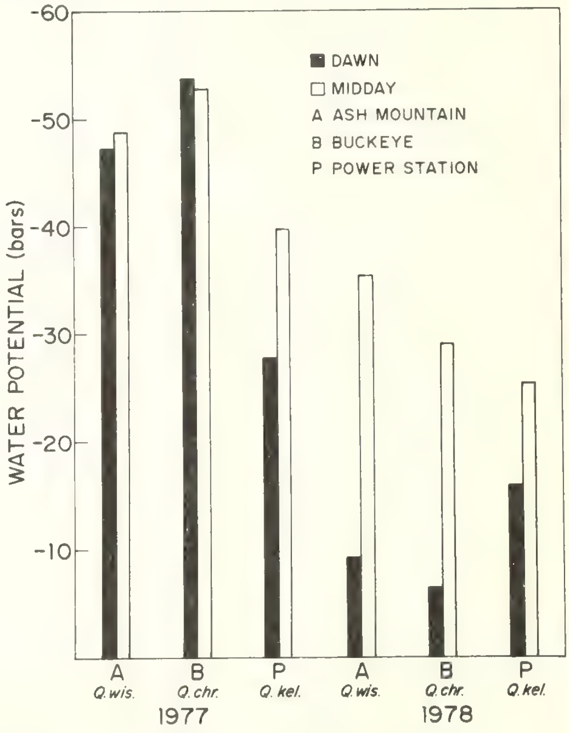

Figure 5--Comparative water potentials of Quercus wislizenii, Q. chrysolepis and Q. kelloggii at dawn and midday for maximum seasonal stresses of 1977 and 1978 in the foothill zone of Sequoia National Park, California.

Even with the heavy spring rains of 1978, however, one population of *Q. douglasii* still developed water stress in excess of 50 bars at midday.

COLD RESISTANCE

Detailed data on the relative cold tolerance of California oak species have not been collected, but some indication of the expected response of our mediterranean-climate species can be gained from studies of cold resistance in species of *Quercus* from the Mediterranean region of Europe. These studies have shown that cold resistance varies considerably with the age of the plant and the nature of the tissue.

For stands of *Quercus ilex*, an evergreen tree comparable to *Q. agrifolia*, mature trees survive temperatures as low as -20° to -25°C so long as cold periods do not last long enough to freeze the thick trunks (Larcher and Mair, 1969). Winter soil surface temperatures of only -4°C are sufficient to kill seedlings, however.

The ability to resist cold in shoots of *Quercus ilex* follows a cyclical pattern of increasing frost-hardening over the first five years of growth (fig. 6). Seasonal tolerance of frost is also quite variable. Shoots of mature plants which survive -25°C in winter may be killed by -5°C in summer. Mature leaves tolerate -15°C in winter but only -6°C in summer. Roots show a pattern of little seasonal change in cold resistance and no change with plant age (Larcher, 1969).

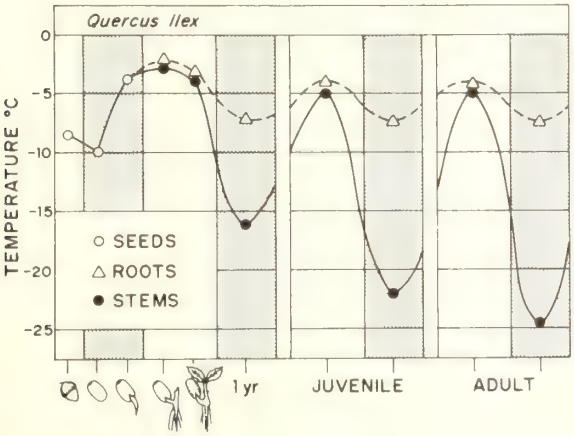

Figure 6--Cold tolerances of *Quercus ilex* in the Mediterranean region of Europe. The open area indicates summer responses, while the shaded areas are winter responses. Redrawn from Larcher (1969).

Two other evergreen oaks from the Mediterranean region, *Q. suber* (cork oak) and the shrubby *Q. coccifera* are slightly less cold resistant than *Q. ilex*. *Quercus pubescens*, a deciduous tree from the same region tolerates temperatures below -35°C (Larcher and Mair, 1969).

HERBIVORY

Herbivory by both insects and vertebrates on oaks may be very great. This herbivory is clearly related to the relatively high nutrient content of oak foliage and the abundant resources oaks represent in many ecological communities. Insect feeding on oaks is generally concentrated in the early spring, coinciding with a period of maximum leaf growth. Insect damage studied in three species of oaks in New York accounts for a 7.0-15.6 percent loss in leaf area (Whittaker and Woodwell, 1968).

The intensity of feeding by lepidopteran larvae on leaves on *Quercus robur* has been shown to be related to chemical and textural changes in the composition of leaves (Feeney, 1970). As leaves mature, tannin content increases from less than 1 percent in the early spring to over 5 percent by the end of the summer (fig. 7) over the same period leaf nitrogen content drops from over 4 percent to about 2 percent. These tannins, concentrated in vacuoles in the palisade parenchyma, have the ability to form complexes with proteins and thereby reduce the availability of nitrogen for insect growth. As a result, summer insect damage to oak leave is greatly reduced from

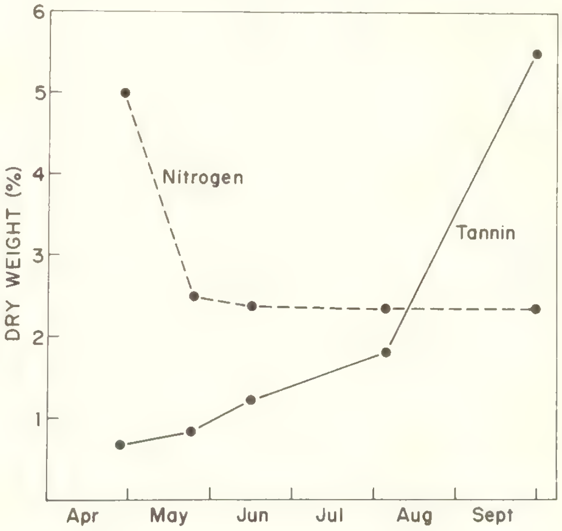

Figure 7--Seasonal progression of concentration (% dry weight) of nitrogen and tannins in the deciduous leaves of *Quercus robur*. Redrawn from Feeney (1970).

what it potentially might be. Parallel studies of predation in relation to leaf characteristics have not been carried out with California oaks. It is interesting to note that damage by leaf miners is proportionally greater in summer than in spring for oak leaves. These insects are able to avoid tannins by feeding in spongy parenchyma tissue and ignoring palisade cells where tannins are concentrated (Feeney, 1970).

Tannins may also be toxic to many grazing vertebrates if large quantities of oak foliage are consumed. Oak toxicity has been a major economic problem in many rangeland areas where cattle, sheep or goats may preferentially consume an almost exclusive diet of young oak leaves, buds and acorns (Kingsbury, 1964).

CONCLUSIONS

Plant growth-form and leaf duration are structural traits which provide important adaptive value for oak species in individual environments. Shrubby growth-forms of oaks are characteristic of habitats where environmental stress is relatively great. These include arid regions (chaparral and desert areas) regions with short growing season (high mountain areas) and nutrient-deficient sites (e.g. as serpentine soils). Tree growth-forms dominate where drought periods are shorter or absent and neither temperature or nutrients are strongly limiting to growth.

Where ground water supplies are available to reduce periods of summer drought stress as in valley or foothill regions, deciduous oaks dominate in California. They are also dominant on more xeric habitats at higher elevations where growing seasons are relatively short. Evergreen leaves, characteristic of the shrubby oaks in chaparral and desert areas, have adaptive value over deciduous leave because of their greater drought tolerance. Since such habitats are commonly low in nutrients, an additional value of evergreen leaves is their greater nutrient use efficiency. This greater nutrient use efficiency also explains evergreeness in serpentine oaks such as *Q. durata*. The adaptive values present in evergreen trees are more difficult to explain since evergreen and deciduous oaks may occur side by side and water does not appear to be strongly limiting. More detailed physiological studies are needed to resolve this question but the basic environmental stresses of water and nutrient availability are clearly still important.

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Quercus chrysolepis

Wildfire and the Geographic Relationships Between Canyon Live Oak, Coulter Pine, and Bigcone Douglas-fir Forests[1]

Richard A. Minnich[2]

Abstract: Analysis of vegetation changes in the eastern Transverse Ranges between 1938 and 1975 reveal contrasting burning regimes in bigcone Douglas fir (Pseudotsuga macrocarpa) and Coulter pine (Pinus coulteri) Forests. Differences in the flammability of these types result from the variable physiognomic and fuel characteristics of associated canyon live oak (Quercus chrysolepis), and strongly influence geographic and sympatric relationships between these species.

INTRODUCTION

Wildland fire does not have a uniform impact on the landscape geographically because the combustibility of vegetation changes spatially with the total habitat. It follows that the geography of some plant species and plant communities may be related to the changing selective role of wildland fire.

A biogeography of conifer forests was evaluated in the eastern Transverse Ranges (east San Gabriel and San Bernardino Mountains), an area of impressive topographic, elevational, and habitat differences (Minnich 1978). Recent vegetation changes due to fire were reconstructed from aerial photography (color infrared, color, black and white) flown between 1938 and 1975 emphasizing the nature of combustion and post-fire recovery for seven conifer forest types.

One finding was that many tree species with divergent adaptations and fire responses live together as plant communities because they are compatible with the fire regime they create. Other species have no range overlap because the fire regime of one is inimical to the other. This paper addresses the relationship between canyon live oak (Quercus chrysolepis), bigcone Douglas fir (Pseudotsuga macrocarpa) and Coulter pine (Pinus coulteri) which live at intermediate elevations between lowland chaparral and mixed conifer forests above. The distribution of the two conifers broadly overlap with canyon live oak but not to one another.

ECOLOGY OF CANYON LIVE OAK, COULTER PINE AND BIGCONE DOUGLAS FIR

Canyon live oak is associated with many conifer forest communities in southern California including Coulter pine, bigcone Douglas fir, mixed conifer forest, and pinyon forest (Minnich 1978; Thorne 1977; Vasek and Thorne 1977). The oak's growth form is quite variable, ranging from shrub to tree, depending on habitat (Sawyer et al., 1977). The shrub form is typically multiple-trunked with crown bases contiguous with the ground surface. Under favorable circumstances it is also a spreading single-trunked tree. A thin-barked species for its size, it sprouts mostly from a subsurface root crown even if the upper canopy is only marginally defoliated by burning or scorching. Horton (1960) and Kittredge (1948) suggest that repeated burning reduces canyon live oak to a shrub physiognomy. Horton also observed that it grows more rapidly to tree physiognomy in mesic habitats where there is also greater chance individuals will withstand passing conflagrations. Where stands are destroyed, however, the area becomes infested with dense chaparral until the oak sprouts mature enough to crowd them out (Horton 1960).

Coulter pine is a medium-sized tree with a spreading pyramidal crown and relatively thick bark. It self-prunes poorly, the crowns of even mature trees normally extending to the ground surface or vegetal understory. It supports massive cones with prominent flattened spurs, mostly at the summit of the tree or the ends of major branches. The cones require two years to mature. Cone opening occurs in midwinter (Critchfield personal communication). Seeds are hard, heavy, and capable of only limited dispersal unless transferred downslope by rolling cones. Seedlings develop best on open mineral soils and are remarkably drought-tolerant, having coarse cotyledons, rapid early photosynthesis, and deep root penetration during the first year (Wright 1966, 1968). It matures rapidly to tree size within several decades and begins bearing cones within 10 to 15 years. Southern California populations are associated with chamise chaparral as well as canyon live oak (Wright 1966, 1968; Wilson and Vogl 1965; Vogl 1976; Hanes 1976; Minnich 1976; Thorne 1977).

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Bigcone Douglas fir is considered a long-lived species found mostly in stable fire-resistant habitats (Gause 1966; Bolton and Vogl 1969; Vogl 1968; McDonald and Littrell 1976). A southern California endemic, this tall conifer has thick bark and long, graceful lenticular branches. Saplings rarely bear cones before 40 years. Pollination occurs in late spring and cones open in August or September. Seed are heavy and only locally dispersed except during strong winds. Canyon live oak is an important associate throughout its range and also occurs as large robust trees with little brush understory (McDonald and Littrell 1976). Although bigcone Douglas fir seedlings are large and coarse, capable of enduring heat stress, reproduction is most successful in the shade of canyon live oak overstory. Growth may be suppressed by shade stress until polesize stage when trees emerge through the canyon live oak layer (Gause 1966). Bigcone Douglas fir is the only southern California conifer capable of sprouting after complete defoliation by fire or other disturbance. Sprouts develop from epicormic buds within the bark layer in the larger branches and along the main trunk. Sprouting success is apparently dependent on the size of the tree (Bolton and Vogl 1969).

PRESENT DISTRIBUTION AND STAND PHYSIOGNOMY

Canyon live oak (W) occurs on steep, shallow soiled terrain over a wide range of elevation from 2000 to 8500 ft. (600-2600 m). It is confined to canyons and north-facing slopes at lower elevations. Above 5000 ft. (1500 m) stands broaden out into a continuous belt which nearly encircles the mountains above lowland chaparral. Canyon live oak cover is open to broken when embedded in chamise chaparral and Coulter pine. It is normally contiguous where associated with bigcone Douglas fir. Coulter pine stands ($\overline{C}$) occur on dry rocky slopes and ridgelines. On the Pacific slope it forms a fragmented distribution from west City Creek eastward to San Gorgonio Pass. On desert drainages, more continuous stands occur on mesic headwaters of the East Fork Mojave River from Lake Arrowhead east to Shay Mountain. Most stands are immature and even-aged in appearance (Table 1). Canyon live oak is an oversized shrub admixed with chamise chaparral dominated by _Quercus dumosa_, _Q. wislizenii_, _Arctostaphylos glandulosa_, _Ceanothus leucodermis_ and _Adenostoma fasciculatum_. Total cover is usually close to 100 percent. Brush and canyon live oak understory on desert slopes is more open and mature as evidenced in data developed from VTM field plots.[3] Few fires have occurred in this region since Forest Service records begin in 1911. VTM diameter class data show that Coulter pines are apparently short lived with only 16 per cent of individuals having a d.b.h. of 24" (0.6 m). Most Coulter pine forests are vertically contiguous with shrub and woodland understory.

Bigcone Douglas fir stands (Bs) are sympatric with canyon live oak throughout its distribution. Forests are long lived. Half of bigcone Douglas fir individuals sampled by VTM workers had a d.b.h. greater than 24" (0.6 m). One third of canyon live oak individuals had a d.b.h. of 12" (0.3 m). Most are tall and single-trunked rather than multiple-stemmed shrubs. Brush cover is minimal and consists mostly of _Ceanothus integerrimus_ and _Cercocarpus betuloides_. Bigcone Douglas fir has a highly fragmented distribution along the mesic coastal front of the eastern Transverse Ranges from the San Dimas Experimental Forest eastward into San Gorgonio Pass. Most populations occupy precipitous slopes and sheltered canyons. Above 5000 ft. (1500 m) stands broaden out with canyon live oak as understory to cover large areas of mostly steep complex slopes transected with cliffs or avalanche shoots, especially in the San Gabriel Mountains and southeastern San Bernardino Mountains.

FIRE HISTORY

The eastern Transverse Ranges have experienced many fires since the original aerial photography was flown in 1938. Recent vegetation

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[3] Vegetation Type Map Survey (VTM). On file, Pacific Southwest Forest and Range Experiment Station. Berkeley, CA. In care of Dr. William B. Critchfield.

TABLE 1 — VEGETATION SUMMARY

VEGETATION TYPE	AERIAL PHOTO DATA					VTM DATA[3]		
	1975[1] AREA	MEAN COVER[2]				SHRUB[4] COVER	PERCENT STEM DIAMETERS >24"[5]	
		OAK	CONIFER	SHRUB	TOTAL		OAK	CONIFER
CANYON LIVE OAK (W)	423.2	45	*	35	75	98	1	*
BIGCONE DOUGLAS FIR-CANYON LIVE OAK (BsW)	111.8	56	40	5	85	13	30	48
COULTER PINE-CANYON LIVE OAK (C̄W)	32.4	35	25	40	80	22	14	16

[1] Total area of vegetation type (in hundreds of hectares)

[2] Percent

[3] Brush plot data of the vegetation type Map Survey. On file, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA

[4] Percent

[5] Tree tally data; see 3/ above.

TABLE 2 — WILDLAND FIRE DAMAGE[1]

VEGETATION TYPE	1938 AREA[2,3]	TOTAL[3] FIRE AREA IN TYPE	DEFORESTATION[3]	DEFORESTATION RATE[4]	RECENT VEGETATION DAMAGE DEFORESTATION RATE (percent of stand)							
					EXPOSURE			SLOPE CLASS (degrees)				
					N	S	T	0-9	10-19	20-29	30-39	40
W	-	-	-	-	73	90	80	-	73	74	83	70
BsW	136.5	91.6	24.7	27	42	40	41	-	63	61	36	10
C̄W	48.2	18.6	15.0	81	86	91	90	-	67	92	91	100

[1] Minnich 1978

[2] Computed from 1938 vegetation map.

[3] In hundreds of hectares

[4] Deforestation/Total fire area in type.

history up to the 1975 aerial coverage shows divergent burning regimes in bigcone Douglas fir and Coulter pine forests and the combustion of associated canyon live oak understory (Table 2).

Canyon live oak stands were very sensitive to fire, even low-intensity ground fires. Its defoliation rate either by char or scorch was a high 78% of stands (by area) in recent fires covered by color infrared aerial photography. The most resistant stands were those which assume tree size proportions in canyon bottoms, north facing slopes, and as open cover at higher elevations (Fig. 1). Shrub-like stands were destroyed in the same manner as chaparral because of the horizontal and vertical contiguity of fuels. There were also numerous islands of yellow-foliaged oak canopies on color infrared photography (CIR) surrounded by burned chaparral indicating that ground fires were able to scorch the overstory without burning them.

The partial fire-retardant character of tree-size oak woodlands appears to stem from several factors, including the large living biomass of individual trees, low dead fuel content of crowns owing to leaf fall in early summer and most importantly, the distance between the crown undercanopy and the ground surface fuels, which may be as much as 15 to 30 ft. (5 to 10 m).

Nearly 60 percent of bigcone Douglas fir forests escaped defoliation in recent fires. Fifteen percent resprouted later, giving a total survival rate of about 75 percent, approximating the long-term survival rate for all fires since 1938. Although this species has the advantage of height over other chaparral trees, its success in avoiding combustion may be better related to its general sympatry with

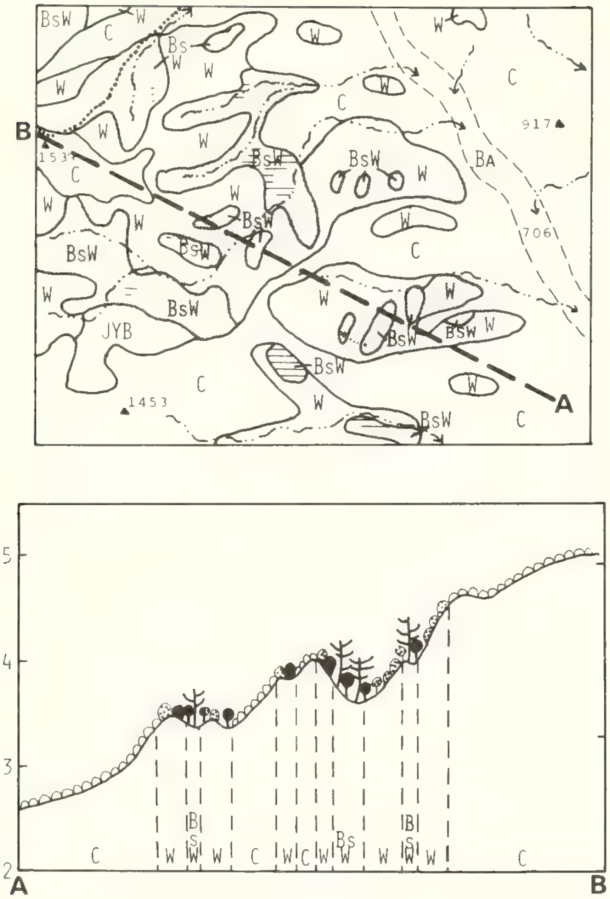

Figure 1. Fire map and profile of Lytle Creek Canyon burned in 1970. Surviving bigcone Douglas fir and tree-sized canyon live oak (BsW) in canyon bottoms (solid line work on profile, stipple on map) are surrounded by destroyed chamise chaparral and canyon live oak scrub on exposed slopes and ridges. Some bigcone Douglas fir resprouted later (slash on map). Elevation (y axis) in thousands of feet. Scale, 1:12,000.

tree-sized canyon live oak woodlands (Fig. 1). These oaks seem to act as a buffer against severe combustion characteristic of nearby chaparral. Analysis of CIR photography shows that the degree of fire injury sustained by bigcone Douglas fir is spatially congruent with the extent of fire damage to the canyon live oak; i.e., areas of surviving bigcone Douglas fir are underlain by either unburned or scorched oak. In all defoliated stands of bigcone Douglas fir, the oak was also burned.

The survival of bigcone Douglas fir was also enhanced by terrain roughness, especially where stands occupy vegetation-free cliffs, talus gullies and rugged canyons. These invariably impeded the momentum and intensity of the spreading conflagration. Survival of bigcone Douglas fir increases dramatically with increasing slope class from 37 percent on slopes less than 20° to more than 90 percent survival on slopes greater than 40°.

In contrast, most Coulter pine-canyon live oak stands involved in fire since 1938 were killed (81 percent, Fig. 2). The deforestation rate is also high for all slope classes. The physiognomy of this vegetation type virtually guarantees its destruction. The chaparral and oak understory normally burned completely and intensely, leaving little above-ground biomass except for largest fuels. Lacking shade stress, Coulter pine crowns extend downward to the

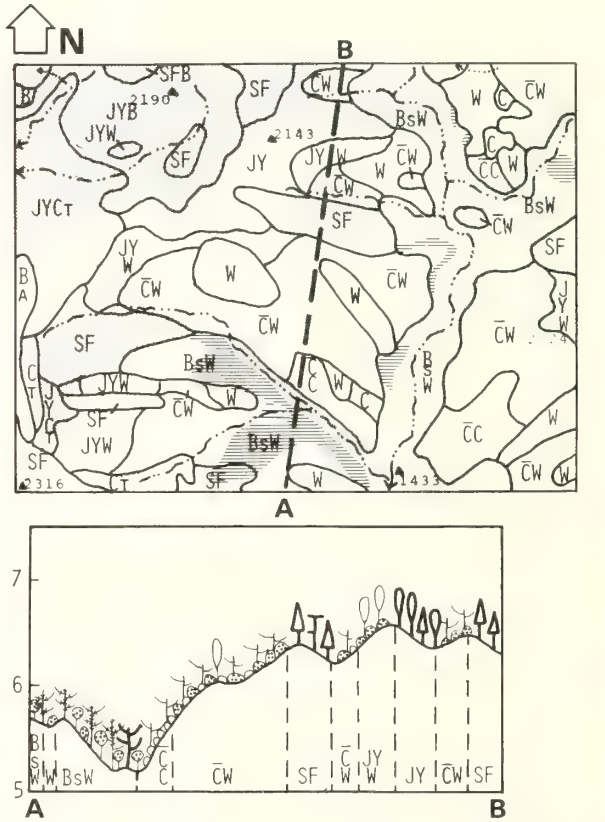

Figure 2. Fire map and profile of Bear Canyon burned in 1970. Sequence of burned Coulter Pine (C̄) and unburned mixed conifer forests (Yellow pine, JY; Sugar Pine-White Fir, SF) on south and north facing slopes, respectively. Coulter pine was destroyed more completely because of the greater abundance of canyon live oak scrub and chamise chaparral understory (C̄W, C̄C). Bigcone Douglas fir groves on cliffs at the bottom of Bear Canyon escaped the burn or resprouted. For explanation of linework, toning, and scale, see Figure 1.

TABLE 3 —POST-FIRE VEGETATION RECOVERY[1]

VEGETATION TYPE	AGE CLASS (yr.)	TRANSECTS (no.)	MEAN STAND AGE (yr.)	TOTAL SHRUB, WOODLAND COVER (percent)	CANYON LIVE OAK COVER (percent)	CONIFER REPRO. FREQUENCY/ 100 m	PERCENT CONIFER SAPLINGS >15 ft (5 m) TALL
CW	0-9	9	4	71	29	3.2	0
	30+	2	43	89	26	7.4	50
BsW	0-9	13	4	63	27	0	0
	10-19	11	18	85	30	0.1	0
	20-29	7	23	75	32	0.6	-
	30+	3	54+	77	75	1.1	50

[1] Compiled from field transects (Minnich 1978).

burning vegetal understory and easily ignite. Many stands also occur on smooth undissected slopes where conflagrations may sustain great intensities without topographic interruptions.

POST-FIRE VEGETATION SUCCESSION

The distribution of canyon live oak changed little between 1938-75 because it sprouts vigorously and stand turnover is minimal. After fire, most individuals sent up numerous stems from a basal woody mass which later developed into a large spherically shaped shrub. Root sprouting was characteristic not only for incinerated individuals, but also for those merely scorched. A few individuals crown-sprouted but only if they were quite large, having adequate bark thickness to prevent cambium damage, and only marginally singed. 1938 and 1975 aerial photographs indicate that the stature of most canyon live oak stands experiencing fire disturbance since 1938 was markedly reduced and in some cases, tree-size assemblages were reduced to shrubs. Cross comparison of stands of different age class show a pattern of rapid early growth, then continuous height extension thereafter, reaching 10 to 20 ft. (3-6 m) after ca. 50 years.

Early post-fire recovery of destroyed Coulter pine forests is visually dominated by rapid redevelopment of sclerophyllous shrub vegetation (table 3). Dominant species were chiefly sprouters including *Adenostoma fasciculatum*, *Arctostaphylos glandulosa*, *Quercus wislizenii* and canyon live oak. There were lesser quantities of shrub seedlings, mostly *Ceanothus integerrimus*, *C. leucodermis*, *C. greggii vestitus*, and *Adenostoma fasciculatum*. Sprouting canyon live oak were 3 to 6 ft. (1-2 m) tall in 4-year-old burns and 5 to 15 ft. (2-5 m) tall in 10 to 20-year-old burns.

There was an abundance of Coulter pine seedlings in nearly every transect covering recent burns including the large Bear fire 50,000 acres (20,000 hectares) which occurred 4 years before field work. Most individuals in this burn were 6-18 inches (10-30 cm) tall and contained 2 or 3 branch whorls suggesting they germinated either 1 or 2 years after the fire. The offspring germinated from seed stored in cones persistent on nearby adults killed by the fire. Abundant slightly scorched open cones were observed on the ground at the top of killed trees. Coulter pine is not a closed cone pine, yet its reproductive strategy appears similar to Knobcone pine (*Pinus attenuata*) which is truly serotinous (Vogl 1968). Because cones appear to open in mid-winter, they were apparently closed at the time of the fire (November). Because cones and seed are heavy, long-range seed dispersal from nearest living populations several miles distant is unlikely. Reproduction was most abundant along roads and trails where soil compaction and surface erosion from subsequent winter rains may have improved seed bed preparation.

Comparison of stands by age class indicates that the pine develops height advantage over associated shrub and woodland species. Individuals averaged 5 to 15 ft. (2-5 m) height after 20 years and 25 to 50 ft. (8-15 m) after 45 years. Cones were produced within 10 years. Second generation saplings beneath mature trees and brush, however, were consistently in poor condition in heavy shade. It appears that, like most yellow pines, this species' regeneration is enhanced by disturbance.

Post-fire crown sprouting of bigcone Douglas fir after the 1970 Meyer and Bear fires became detectable in subsequent aerial photography flown 2 to 3 years afterwards. Sprouting success appears dependent primarily on site severity of combustion rather than tree-size class. As a rule, scorched stands with persistent dead foliage resprouted, but severely burned stands were killed. Moreover, field reconnaissance of stands burned recently by the 1975 "Village" fire near Mt. Baldy, revealed a striking sprouting success among polesize trees and saplings as small as 10 ft. (3 m) in height. In a number of individuals, sprouting proved to be abortive after one season, but others recovered rapidly to full crown within 2 to 3 years.

Areas of bigcone Douglas fir deforested since 1938 were converted into canyon live oak ranging from an open stand of root sprout rosettes mixed with chaparral in recent burns to contiguous woodlands in stands older than 30 years (table 3). Four years after the 1970 Bear and Meyer fires, destroyed stands were dominated by the carcasses of bigcone Douglas fir and canyon live oak. Living biomass consisted of canyon live oak sprouts 3 to 6 ft. (1-2 m) in height and seedlings of _Ceanothus integerrimus_ and _C. leucodermis_. In older stands 15 to 30 years of age, shrubs and canyon live oak formed a relatively impenetrable chaparral 3 to 10 ft. (1-3 m) in height with emergent oaks as tall as 15 ft. (5 m). In stands older than 30 years, robust canyon live oak trees, still multi-stemmed and shrub-like, formed a closed canopy 15 to 30 ft. (5-10 m) tall. Chaparral understory was not present except for carcasses of _Ceanothus_ spp. which died _en masse_ at about 30 years of age.

In contrast with disturbed Coulter pine forests, bigcone Douglas fir reproduction in deforested stands was practically non-existent. No offspring was found in stands less than 19 years old (24 transects covering 2995 m). A few seedlings and saplings were found in stands at least 55 years old. The reasons for this are unclear. Cones and seed are killed by fire. Long-distance seed dispersal from living populations by wind may be inefficient because the seed is heavy. Reproduction may also be inhibited by the lack of shade due to the combustion of canyon live oak, a time-consuming condition for shade-tolerant bigcone Douglas fir which must await the redevelopment of oak overstory. Field reconnaissance elsewhere in the study area suggest that reproduction was most conspicuous in the least disturbed habitats free of fire for 50 years.

DISCUSSION

Analysis of the vegetation history of the eastern Transverse Ranges for the period 1938-75 suggests that the rate of deforestation and recovery of bigcone Douglas fir and Coulter pine forest is different. This is explained by the variable physiognomic and fuel characteristics of canyon live oak in promoting contrasting fire regimes. Coulter pine is usually sympatric with shrub canyon live oak admixed with chamise chaparral and effectively adapts to frequent severe fire through its closed cone tendency during the fire season, drought tolerance, and vigorous regeneration to reproductive stage within two or three decades. The life span of shrub species is greater than the interval between fires; shrubs and therefore a permanent part of the vegetation which actually contribute to the deforestation of Coulter pine overstory. Frequent intense disturbance, therefore, appears to be compatible with this species.

Bigcone Douglas fir occupies steep slopes with relatively non-flammable tree-sized canyon live oak woodlands. It frequently escapes fire or sprouts after moderately intense fires. The interval between defoliating fires is long enough for the maturation of slow growing saplings and concomitant development of tree-sized canyon live oak which root sprout. Shrub seedlings which germinate after fire disturbance, mostly _Ceanothus_, are short-lived and do not contribute as fuels to the next fire. Bigcone Douglas fir reproduces best in the shade of the oak canopy. Because of its poor reproductive capacity, it cannot compete with highly flammable chamise chaparral where the frequency of lethal fire events exceeds its regeneration time. Instead, bigcone Douglas fir refuges in canyons with canyon live oak, especially at lower elevations.

In spite of their common distribution by elevation and association with canyon live oak, bigcone Douglas fir and Coulter pine are seldom found together. The stability of bigcone Douglas fir canyon live oak forests would appear to be adverse to Coulter pine. Clearly, if stands normally escape fire, then shady undisturbed conditions would not be conducive for the regeneration of Coulter pine which reproduces and grows best under disturbed mineral soil conditions in full sun. Moreover, the occasional circumstances of stand defoliation would select in favor of bigcone Douglas fir because of its sprouting habit when Coulter pine would be killed. Conversely, the intense disturbance pattern associated with chaparral or canyon live oak scrub would select for Coulter pine because it is a good pioneer compared to bigcone Douglas fir.

This is seen where their distributions overlap and their sympatry with canyon live oak. Bigcone Douglas fir tends to occupy the most sheltered, interrupted slope surfaces where canyon live oak is relatively non-flammable owing to its size. On exposed smooth brush-covered slopes where Coulter pine is found, canyon live oak is a fuel contributing to the disturbance necessary for the pine.

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The Fire Resistance of Engelmann and Coast Live Oak Seedlings[1]

Gerald E. Snow[2]

Abstract: Southern oak woodlands have probably experienced more frequent fires in the past than during the last 30-50 years. Mature Engelmann (Quercus engelmanni) and coast live oaks (Q. agrifolia) appear to survive most fires except the hottest brush fires. However, differential seedling and sapling resistance to fire may have an influence on where these species grow. Seedlings of both species were burned under controlled conditions. Buds of Engelmann oak are better protected and/or more resistant to fire and heat than those of coast live oak. An analysis of 15 Vegetation Type Map survey profiles in southern California of stands containing either or both of these species would tend to indicate Engelmann oak grows more frequently in or next to more fire prone habitats. Woodlands with Engelmann oak are quite rare and many have already been and are continuing to be lost to agricultural and urban development.

INTRODUCTION

Southern oak woodland (Griffin 1977) occurs in patches surrounded by an almost continuous sea of brush (chaparral) while to the north the chaparral occurs primarily as islands surrounded by oak woodland (Benson 1957). Since chaparral has had such a long history with fire (Aschmann 1976 and Hanes 1977) one might expect oak woodlands to be influenced in composition and between-species distribution by fires also. Up until the last 30-50 years fires were more frequent, resulting in less fuel to carry hot destructive fires into woodlands (Aschmann 1976 and Dodge 1975). Due to fire supression with resulting fuel buildup, we have recently experienced fires in southern California which have destroyed half of the oaks in some woodlands (Dodge 1975).

The 2 major oak species in southern oak woodlands are Engelmann oak (Quercus engelmanni Greene) and coast live oak (Q. agrifolia Nee) the former often growing in open savannas called the "Engelmann oak phase" and the later growing in denser more widespread woodlands termed the "coast live oak phase" (Griffin 1977). Some of the factors influencing the reproduction and distribution of these 2 species on the Santa Rosa plateau in the Santa Ana Mts. were inhibition of seedling establishment by cattle in open areas (especially Engelmann) and the consentration of coast live oak around rock outcrops (especially in cracks and the north side) due to ground squirrel transport and high moisture requirements for germination (Snow 1973).

This paper presents some evidence that the differential response of these 2 species to fire during establishment may be an additional factor influencing their distribution on the Santa Rosa plateau and in woodland communities in southern California.

MATERIALS AND METHODS

As an index to the resistance of the 2 oak species to fire, greenhouse grown seedlings were observed for resprouting following 2 intensities of burning. Three wooden boxes were filled with vermiculite and 10 acorns of each species per box were planted alternately 1.5 cm below the surface in January 1971. After germination was completed in the laboratory at 20°C the seedlings were transferred to the greenhouse under controlled day temperatures of 21 to 24°C and a night temperature of 16°C. The seedlings were watered to field capacity twice each week with 1 of the waterings made with a nutrient solution.

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[1] Presented at the symposium on the Ecology, Management and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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After the seedlings were 4 months old, the vermiculite in the boxes had settled about 1.5 cm. About 1.5 cm of field-collected soil was added to the top of the boxes, watered and smoothed out and allowed to dry in order to provide a more realistic soil surface for the burn treatment. In order not to disturb the dry soil surface, the boxes were subirrigated once a week.

After the seedlings were 5 months old (up to 15 cm tall) they were prepared for the burn treatment. All of the seedlings stems were clipped from between 1.5 and 2.5 cm above the soil surface thereby removing all the leaves. This was done to provide an even exposure of the stems and soil surface to the burner heat and flame. One of the 3 seedling boxes was not burned in order to provide a control for the clipping treatment. Of the 2 remaining burn treatment seedling boxes, 1 was treated to simulate a light grass fire and the other a more intense grass fire.

The intensity of the burn treatments was monitored using 3 thermocouples 20 cm apart at the soil surface in each box. The thermocouples were positioned so that 1 side was exposed to the air and the other in contact with the soil. The temperatures were continuously recorded using a Sanborn 350 multiple channel recorder.

To effect the burn treatments a seedling box was placed in a gravel bed over which a propane burner was pulled on a track at an adjustable constant rate of speed. The burner was a one-twelfth scale model of the burner box described by Bonlie and Kirk (1971). For the light burn treatment the burner was passed over the seedlings 10 cm above the soil surface at a rate of 10 cm per second resulting in an average peak soil surface temperature of 85°C and 4 seconds above 65°C. For the more intense burn treatment the burner was passed over the seedlings at the same height but with more flame and half the speed of the light burn treatment. This resulted in an average peak soil surface temperature of 175°C and 20 seconds above 65°C.

After the clipping and burn treatments the seedlings were maintained for 2 months under the greenhouse conditions described above. At weekly intervals any new shoots were noted at or above the soil surface and the distance in millimeters from the soil surface to the new shoot base above or below the soil surface was recorded.

The occurrence of the 2 oak species in different woodland types in southern California and the immediately adjacent habitats was tabulated from 15 profiles of California vegetation based on "Vegetative Type Maps" (VTM) surveyed between 1928 and 1934 (Critchfield 1971 and U.S. Forest Service 1934).

RESULTS AND DISCUSSION

The resprouting curves for the clipping and burn treatments are presented in figure 1. Engelmann oak resprouted more rapidly after clipping (100 percent after 1 week) than did coast live oak (50 percent after 1 week; 100 percent after 2 weeks). Engelmann resprouted more quickly and completely after the burn treatments (100 percent after 3 weeks) than did coast live oak (80 percent after 6 weeks). The largest difference between species and treatment occurred 2 weeks following the burn treatments. Then Engelmann and coast live oak had 90 percent and 10 percent resprouting respectively following the light burn while after the more intense burn they had 60 percent and 10 percent resprouting respectively.

In the control seedlings all the resprouts were well above the soil surface from the highest buds remaining on the clipped stems. In the light burn treatment the mean distance from the soil surface to the new shoot base was 2.2 mm below the surface for Engelmann oak (ranging from 4 mm above to 8 mm below) and 5.4 mm below the surface for coast live oak (ranging from 3 mm above to 14 mm below). In the more intense burn treatment this mean distance was 5.2 mm below the surface for Engelmann oak (ranging from the soil surface to 10 mm below) and 7.8 below the surface for coast live oak (ranging from 4 mm below to 11 mm below). Although Engelmann oak tended to have buds resprouting closer to the surface than coast live oak, in the burn treatments the means were not significantly different at the 0.05 level.

Tothill and Shaw (1968) recorded soil surface temperatures under fire in grass pastures in Australia. They found that these temperatures varied considerably according to the fuel supply and environmental conditions. The temperatures they recorded ran from 75°C to well over 220°C but peak temperatures above 100°C had a duration of a minute or less. Temperatures they recorded 12 mm below the surface seldom exceeded 65 to

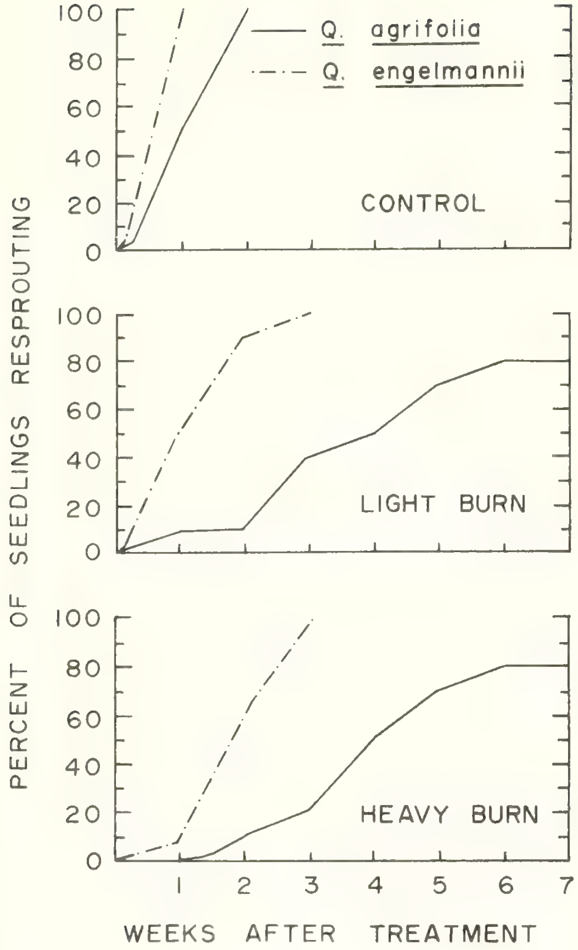

Figure 1--The resprouting curves of coast live oak (Quercus agrifolia) and Engelmann oak (Q. engelmannii) after being treated by clipping (control), light burning, and heavy burning.

70°C. Heyward (1938) recorded surface and below-surface temperatures in an open pine forest burn with grass understory. At 12 mm depth there was very little rise in temperature. With drier soils there were higher surface temperatures recorded but less heat conducted downward. Bentley and Fenner (1958) recorded a maximum of 121°C at the soil surface in a woodland range fire. Lawrence (1966) recorded 280°C "on a grassy surface" in a California chaparral fire. Based on these previous studies the peak surface temperature of 85°C used in the light burn in this study would be considered quite cool for a grass fire. The 175°C peak used in the more intense burn might be considered a moderate or hot surface temperature for a grass fire.

In this study the two intensities of burning had little effect on the completeness of recovery; mainly an effect on the speed of recovery which would be related to the depth from which a shoot might come from below the surface until it was noted at the surface. Even though the distances measured from the soil surface to the base of the new shoots were not significantly different between the 2 species due to the wide range of values, only half of the Engelmann oak buds above the soil surface were killed with the light burn treatment while 80 percent of the above surface buds on coast live oak were killed with this treatment. In the more intense burn treatment the coast live oak buds 4 mm below the surface were the highest buds on the stem to resprout while 40 percent of the Engelmann oak buds resprouting were between this level and the soil surface. Apparently the buds of Engelmann oak are better protected and/or more resistant to fire and heat than those of coast live oak. Also the buds of the cotyledonary node (the lowest point on the stem from which new shoots normally arise) of Engelmann oak are about 14 mm below those of coast live oak due to the self-planting mechanism of Engelmann oak (Snow 1973). With a dry soil surface for insulation I would expect Engelmann oak seedlings to survive rather intense grass fires.

While mature trees of both species probably survive most fires (Lawrence, 1966; Wells, 1962) saplings may be more vulnerable. On some saplings of both species that I cut off near the ground (4.0-7.5 cm diameter and 15 to 23 years old), the bark (live and dead) of Engelmann oak was more than twice as thick (5.7 mm) as the bark of coast live oak (2-3 mm). I would expect that the thicker bark of Engelmann oak saplings would afford them more protection from fire than coast live oak saplings. Lawrence (1966), studying the effect of chaparral fires in the foothills of the Sierra Nevada in California, found that the insulating effect of cracked and fractured granite boulder outcrops was sufficien to protect several woody species that would otherwise have been destroyed. The protection from fire afforded to coast live oak by being associated with granite rock outcrops especially in cracks or fractures within outcrops may be another explanation for their occurrence in these locations on the Santa Rosa plateau.

From the southern California VTM survey profiles (478 km total length) only 13 stands of woodland containing Engelmann oak occurred while 111 stands of coast live oak below 1,000 meters elevation were noted. The percent occurrence of each species in 4 woodland types ranked from the highest fire frequency (historically) to the least were:

	Engelmann Oak	Coast Live Oak
Mixture or mosaic of grass or coastal sage	23	23
Mixture or mosaic of chaparral	8	2
Largely closed canopy	62	37
Riparian	8	39

Both species may be excluded from chaparral due to the more intense heat generated in chaparral fires. Debano and Conrad (1978) recorded soil surface temperatures in chaparral fires more than twice that used in this study simulating a moderately hot grass fire. Fires in closed canopy woodlands would usually be ground fires similar to grass fires.

I created the riparian woodland type out of the closed canopy woodland of the VTM survey when either species of oak was in a canyon bottom and associated with a typical riparian species such as cottonwood, sycamore, alder or willow. It is in this woodland type where the greatest difference between these oaks is seen. This occurrence of coast live oak in wetter sites and Engelmann oak in drier has also been noted for all of the Santa Ana Mountains (Lathrop and Thorne 1978). Because of Engelmann oak occurrence in more dry habitats it would more likely be exposed to fire. Plumb (1979) has noted however that mature coast live oaks are the most fire resistant of all other southern California oak species (mature Engelmann have not been evaluated).

A tabulation of the vegetation types (from the VTM survey profiles) next to oak woodlands indicated 65 percent were chamise chaparral for woodlands with Engelmann oak present but only 37 percent when coast live oak was present. Coast live oaks were associated with 6 other vegetation types while Engelmann was associated with only 3. The other vegetation types adjacent to Engelmann containing woodlands were grassland, coastal sage and agricultural or residential. Most of these woodlands have been or are being lost to agricultural and urban development. Protection of the few remaining "Engelmann oak phase" woodlands should be a high priority item for oak management in southern California.

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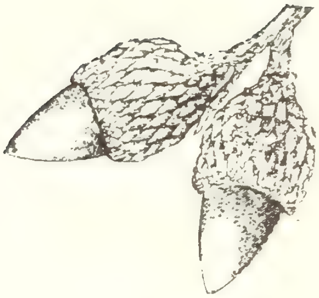

Quercus wislizenii

Inventory and Distribution Records of Oaks in California[1]

Timothy E. Paysen[2]

Abstract: Inventory and distribution records for California's oaks are poor. Our requirements for information about California oaks have been evolving, but classification systems and related inventory systems have not kept pace. Unless we understand and promote the interactive data communication process, the inventory and distribution records on California's oaks will not improve. Once we have clearly established our information requirements, as by developing inventory models, we can use existing technology to fill the gaps in our knowledge.

INTRODUCTION

Our knowledge about the distribution of California's oaks is clearly inadequate. We have a general idea of where we may find the various species of oaks that grow in the State of California; we don't know how many of each species we will find, nor do we know very much about their condition and physical characteristics.

Why is this true? I believe it is because our knowledge of oaks, like that of any resource, results from the interaction between our information requirements and the response that is made to them. We do not know enough because we have not properly determined what we need to know.

In this paper, I will show how our failure to define our needs has affected the inventory and distribution records of oaks in California. The relations between information needs and the activities that lead to development of a data base are diagrammed in figure 1. All these activities reflect a set of requirements. Exploring the relationships shown, in terms of oak distribution, will help us to see how future efforts to improve our knowledge should be directed.

INVENTORIES AND INFORMATION NEEDS

Current Information

An understanding of oak distribution begins with species range. The ranges of California's oaks are well documented. We can follow historical references from the expedition records of early California travelers,[3] through the time of Kellogg and Greene (1889) and Cooper (1922), to current "discoveries" of investigators who encounter oaks in the field. Together, these form a pattern of oak distribution in the State of California that is controversial only in minor points. The information has been well summarized for the tree species of oaks by Griffin and Critchfield (1972).

Information on the specific areal distribution of individual oak species within their ranges is less easily available and our needs are less clearly defined. Are we interested only in extensive, dense stands of oak trees, or also in sparsely scattered stands, or even in scattered individuals within a matrix of other species? Until we can answer this question, our knowledge of oak distribution will be rather shallow. Isolated inventories provide us with some answers (see, for example, Bolsinger 1980 and McBride 1973), but a comprehensive account of oak distribution does not exist.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Research Forester, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, Calif., stationed at Riverside, Calif.

[3] Extracts of these records are in the files of A. E. Wieslander, available at the Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

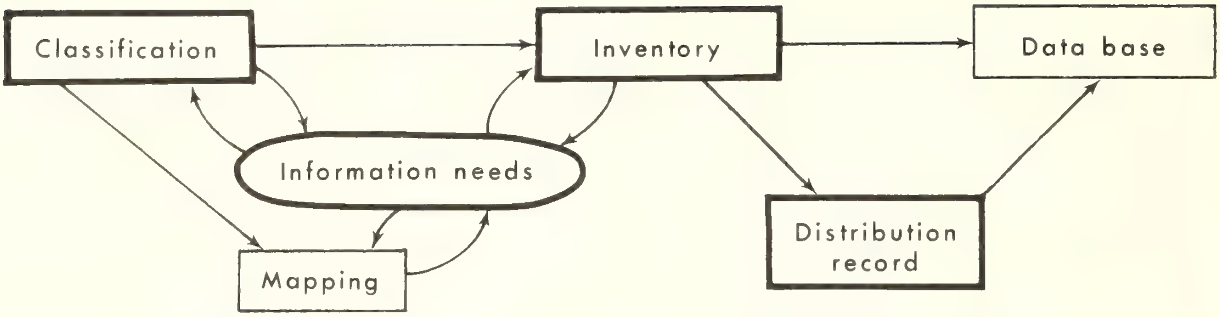

Figure 1--Our knowledge about any given resource is the result of an interactive process. The definition of information requirements is a key element, linking the abstract (classification) to the tangible (data acquisition, storage, and retrieval). This paper is primarily concerned with the elements emphasized.

When anyone asks how many oaks we have in California, or wants more technical details about their numbers, we have little choice than to turn to a 1946 Forest Survey release (Wieslander and Jensen 1946) and quote the number of acres covered by the Woodland (hardwoods) vegetation type. We may then add some qualifying statement that reflects our guess as to the questioner's reason for asking. We can only assume that some proportion of this Woodland type is oak. Furthermore, we must assume that an unknown proportion of other vegetation types mentioned in the publication, such as Woodland-grass, Pine, and Chaparral, contain oak. And, of course, we don't know the density of oaks in any of these types, nor do we know anything about the type structure in general.

Classification and Inventory

If we reconsider the information diagram (fig. 1), we see that classification is the first step in the process. General information requirements usually stem from an ill-defined classification system, based on recognition of primitive traits. Once these requirements have been specified, a formal classification emerges. More definite information requirements then generate inventories, with the target of each inventory directly defined by a specific information requirement. The framework of these inventories is defined by the classification system. The arrows in the diagram point up the two-way process.

A classification system is simply the embodiment of our concept of a particular set of things, and it provides a language for communicating this concept. The very basic unit that we call an oak community, a stand of oaks, or an element of an oak vegetation type, is defined and limited by the classification system we use. If we work with a formally defined system, our concept is formally defined, and we can test its adequacy. If we work with a loosely defined system, our concept is loosely defined, and we really don't know where we are.

To see how our dearth of knowledge is related to classification, consider the major categories used in a number of prominent classification systems to directly or indirectly address California's oaks (table 1). Each system represents the perspective of a particular resource management function, organization, or discipline. Consider also the selected lists (table 2) of formally recognized oak species; these lists are associated with the classification systems in Table 1, or, more generally, with the functions, organizations, and disciplines represented by those systems.

An interesting picture emerges. Table 1 reveals that the concept of oak "types" or oak "communities" is viewed from a number of different perspectives by resource management professionals. Of the classification systems in Table 1, four come from a single organization, the Forest Service, but each represents a different viewpoint. Each breaks down the broad vegetation categories with a different degree of precision. The names of the classes that could include oak as a component represent unique functional perspectives: (1) commercial timber value, (2) range habitat, (3) a global synthesis of each, and (4) a structural breakdown of vegetation using physiognomic criteria. Formal recognition of specific oak communities or vegetation types (those identified by a given species of oak) is limited to a small number of geographic "types" within the Forest Survey system. These are categories included for completeness; however, no commercial timber value is implied for these oak species.

The Society of American Foresters (S.A.F.) system is not directly represented by a species list in Table 2, but it represents the perspective of a national forestry society, and

Table 1--Categories in vegetation classification systems that specify or include California's oaks.

Forest Survey Handbook (U.S. Dep. Agric., For. Serv. 1975)			Range Analysis Handbook (Forest Serv. 1969)	RPA Assessment (Forest Serv. 1975)		VTM Survey (Critchfield 1971)	Society of American Foresters (1954)	California Plant Communities Munz (1963)	
Geographic Forest Type (GFT)	Oak reference in GFT	Local types (GFT)	Vegetation type	Category	Classification	Vegetation types	Cover types	Vegetation type	Plant community
Redwood	Tanoak	---	Broadleaf trees	Forest types	Commercial timber	Chaparral	Oak-madrone	Coniferous forest	Redwood forest
Hardwoods	Other western hardwoods	California black oak	Woodland-chaparral	Nonforest type	Western hardwoods	Timberland-chaparral	California black oak		Douglas-fir forest
		Canyon live oak				Woodland-chaparral	Canyon live oak		Yellow pine forest
		Oak-madrone				Woodland-sagebrush	Digger pine-oak		
		Chaparral				Woodland-grass		Mixed evergreen forest	Mixed evergreen forest
Noncommercial types	Chaparral	Chaparral (with *Quercus* spp.)				Woodland			
						Pine and pine/Douglas-fir		Woodland savannah	Northern oak woodland
									Southern oak woodland
									Foothill woodland
								Chaparral	Chaparral
								Desert woodland	Pinyon-juniper woodland

Table 2--Species of California's oaks recognized in major source documents relating to the distribution or inventory of oaks and other flora. These lists can be associated directly or indirectly with the classification systems in table 1.

Quercus species	Physical characterisics				Forest Survey Handbook (1975)	Range Analysis Handbook (1969)	Wieslander and Jensen (1946)	Munz (1963)	Griffin and Critchfield (1972)	Little (1971, 1976)	
	Ever-green	Decid-uous	Tree	Shrub							
agrifolia	X		X		X		X	X	X	X	
x alvordiana	X		2/	2/			X	X	X		
chrysolepis	X		X		X	X	X	X	X	X	
douglasii		X	X		X	X	X	X	X	X	
dumosa	X			X		X	X	X			
dunnii1/	X			X				X			X
durata	X			X		X	X	X			
engelmanii	2/	2/	X		X		X	X	X		X
garryana		X	X		X	X	X	X	X	X	
kelloggii		X	X		X	X	X	X	X	X	
lobata		X	X		X		X	X	X	X	
macdonaldii		X	X					X			X
x morehus	X		X					X	X		
sadleriana	X			X				X			
tomentella	X		X					X	X		X
turbinella	X			X				X			X
vaccinifolia	X			X		X	X	X			
wislizenii	X		X		X	X	X	X	X		X

1/Recognized as _Q_. _palmeri_ in Munz (1963).

2/Listed in either category, depending on source.

serves as a point of reference. In its treatment of oak vegetation classes, the S.A.F. system offers little more than the Forest Survey system does. The reasons for this are not obvious since the S.A.F. perspective is not limited to timber production. The system was designed, however, to characterize major forest types that occupy "large areas in the aggregate" (Soc. Amer. For. 1954), which explains why its treatment of western oak types or oak communities differs little from that of the economics-oriented timber survey system. Both systems must take on a somewhat global perspective, and individual western oak species do not dominate extensive land masses.

The one "neutral" plant community system—that of Munz (1963)—hints at the importance of oaks, but does not address them by species. Munz did not intend to be more precise than this; he wanted to provide a plant community classification system at a very general level.

It is interesting that none of the classification systems identifies communities or types specific to the oak species recognized in the species list associated with it (except for Quercus kelloggii and Q. chrysolepis, both represented in the Forest Survey system and the S.A.F. system). For some species, this is probably reasonable, since not all oaks dominate the stands in which they grow.

A functional and organizational disagreement on the significance of the various species is evident from Table 2, but there is inconsistency between the lists that can't be entirely explained by such perspectives. For example, the Range Analysis Handbook does not recognize Quercus lobata nor Q. agrifolia even though they are important components of oak-grass communities in many parts of the State. These two species are more characteristic of rangelands than are many of the other species listed in the Handbook.

Together, Tables 1 and 2 show that in broad-scaled inventories, California's oaks are relegated to a nebulous "other" category. They do not fit into the classical commercial timber pattern, and therefore do not appear in timber-oriented classification systems. Oaks often appear as elements of range ecosystems, but their treatment in range-oriented classification systems is little better than that in the timber systems.

Although these conclusions are not surprising, their implications may not be fully appreciated. What we as individuals and as professionals see when we survey vegetation depends strictly on the classification system that we use. The framework used for data collection, and the categories used for data storage, are directly linked to classification.

Masking in Inventories

Some of us may not like to admit that we inventory what we think is there—it sounds unscientific; but there is no other way.[4] The focus of an inventory, the way sampling is designed, and often what we do and do not measure, are all related to concepts embodied in the classification system that we use. If we do not recognize an oak community, we are not going to inventory it. We may measure oak trees, but the information that defines a community will often be masked. This brings us to another relation between inventories and information needs: we must be able to single out communities that, while dominated by species other than oaks, have oaks as integral components.

An interesting example is found in a recent sampling study (Paysen 1978). The study area was in a portion of the San Bernardino Mountains, and covered a variety of vegetation types (fig. 2). The area is commonly described as one containing distinct zones of soft chaparral or coastal sage, chaparral, and conifer forest or mixed conifer-hardwood forest. It is not an area that we would normally describe as an "oak area"—a place that is dominated by the genus Quercus. Yet, the data reveal an overwhelming occurrence of oaks—not only in numbers, but in the biomass that may be assumed to be present, that is, potential biomass.

If we consider all of the major species found in the area (excluding annuals that were unavailable during the time of sampling), and look at the live oaks as a group, we see that the presence of the live oaks is greater than that of any other species (fig. 3). Grouping the different species of live oaks in this manner may seem a bit unfair, but as I am addressing the presence of oaks in general, the grouping is valid. Black oak (Q. kelloggii) has been charted as a distinct species. Furthermore, the presence of black oak compares admirably with that of each of the other species; as a matter of fact, the data imply that it is the most ubiquitous tree species in the area. If the volume of space occupied by the plants is used as a relative indication, the live oaks have more potential biomass than any other species in the study area (fig. 4), and black oak again holds its own quite well when compared to the other species.

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[4] Exceptions are exploratory activities such as "botanizing," which differ from the formally defined inventory process, but are probably the best source of our information on species ranges.

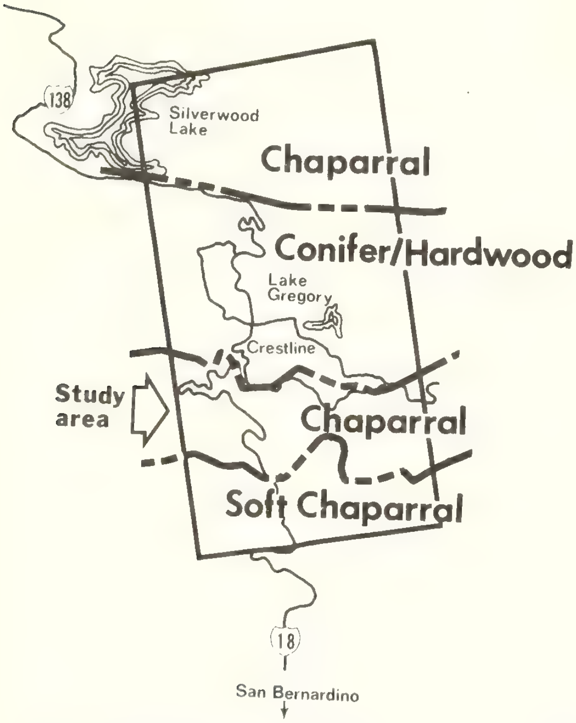

Figure 2--Vegetation zones in the San Bernardino Mountains study area were found to contain large numbers of oaks.

Looking at these results, we realize that a review of maps, classification systems applied to the area, and distribution records would not give a clue to the importance of oaks in this area. The oaks are masked in the record by such terms as "chaparral" and "conifer forest." There is nothing that would provoke a request for inventory data on oaks in that portion of the San Bernardino Mountains. Such a request could only come from someone who has firsthand knowledge of their importance as components of the vegetation cover.

The Inventory Model

The relation between inventories and information needs raises another question: How are we going to get the information we need about oaks? Assuming that we can recognize oak communities and communities wherein oak is an important associate, we can go out and count oaks. But, what if we want productivity information? What if we want information on suitability for a particular management objective? We cannot get these kinds of information without the appropriate inventory models and the appropriate identification criteria.

Inventory models allow us to determine the amounts of a particular resource, or more commonly of a particular resource value, from a functional perspective, by measuring easily obtained parameters in the field. The required information might be board feet of timber, pounds of forage, or acres of multiple-stemmed trees suitable for a particular recreation activity. Until our information requirements clearly state the kind of productivity that is needed, and the viewpoint for assessing suitability (say, recreation use or fuelwood use), we will not be able to develop identification criteria and inventory models. And we will not have our inventories.

After living so long with timber-oriented inventory models, we are shocked when we realize that we have to start from first principles in developing site index curves, and productivity tables for trees that we have been looking at all of our lives. Work in these areas is just beginning (Pillsbury and Stephens 1978, Powers 1972). One thing is clear: we will have to define such concepts as growing site and productivity for oaks in other than timber production terms. The relation between board feet of merchantable timber and cubic feet of fuelwood, for example, is not direct. Neither are the number of trees per acre on good timber site and the number of trees per acre on good recreation site equivalent measures. Our current interest in oaks, in itself, is not enough to generate inventory data and complete distribution records as I have defined them here. We must develop appropriate systems by which to recognize oak communities, and communities with strong oak associations. We must then proceed to develop inventory models that will address our specific requirements. We then have to adjust our management focus in a way that will allow oak inventory requirements to receive an appropriate priority. Only then can an adequate inventory of California's oaks proceed.

Available Tools

Once we have developed inventory techniques and inventory rationale, the job of collecting data should be straightforward. California's oaks have a distinct inventory advantage over many other species--they are easy to find. Remote sensing products that are readily available provide an easy means of identifying stands of oaks. Infrared photography, in particular, is a useful tool. By virtue of their structure and leaf

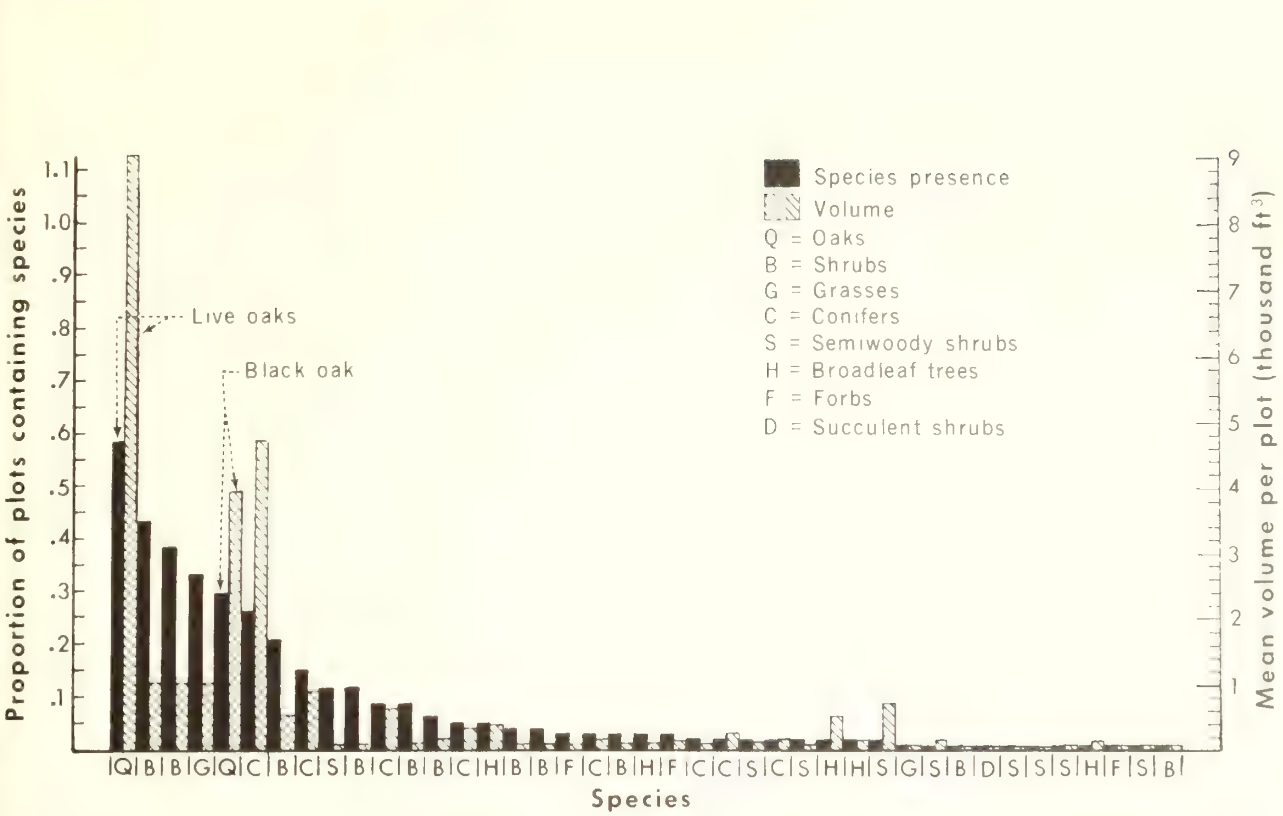

Figure 3--The importance of oak species in the San Bernardino Mountains study area is evident from their presence in relation to other plants, and from their mean volume, which can be viewed as a relative indicator of biomass. Each set of bars represents a different species, except that live-oaks include _Quercus agrifolia_, _Q. chrysolepis_, _Q. dumosa_, and _Q. wislizenii_.

configuration, oak trees stand out clearly within stands of conifers, within chaparral, and in grasslands. We can take advantage of small-scale imagery for sample layout work and rough estimation, and use large-scale imagery for detailed inventory work.

EVOLVING INFORMATION NEEDS

The relation of information requirements to classification systems is a continuing one. Slowly, as inventories proceed, and as we begin to look at resource systems in greater depth, our information requirements change, eventually reaching a point at which they no longer call for additional inventories driven by the original formal classification systems. Then these systems are modified, or even replaced, to accommodate the new set of information requirements.

This does not always proceed at a steady rate. We sometimes let existing classification systems--and their secondary products, such as maps and inventoried data--define our information requirements. The result is a kind of holding pattern, which inhibits recognition of new or emerging lines of investigation of the resource.

We can identify the evolutionary process in the development of oak inventory. Organizations that deal with large-scale resource inventory are just beginning to adopt classification systems that allow recognition of oak communities to some degree of depth[5/] (Paysen and others 1980, Browne and Lowe 1974). These systems will provide the appropriate framework for collecting data, and "pigeon holes" for storing data; they will encourage others to begin to ask questions about the oak communities that are being recognized; resource inventories will be able to take on a new dimension.

In summary, although the present state of our knowledge regarding the inventory and distribution of California's oaks is perceived as being poor, this cannot be established as fact until our information requirements are clearly stated. Only then will we be able to evaluate the state of our knowledge, and establish the links in the information process. Adequate classification systems, and responsive inventory systems and techniques will provide

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[5/] Driscoll, Richard S., J. W. Russel, and M. C. Meier. Recommended national land classification system for renewable resource assessments. Unpublished report on file, Rocky Mountain Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Ft. Collins, Colo.

the inventory and distribution records that are needed.

We have the tools and technology needed to fill the gaps in our knowledge; all we have to do then is identify the gaps.

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Quercus sadleriana

Quercus sadleriana R. Br. Campst., Its Distribution, Ecology, and Relationships to Other Oaks[1]

Gilbert Jerome Muth[2]

Abstract: Quercus sadleriana R. Br. Campst. is a relict endemic of the Klamath Ranges of northern California and southern Oregon that is a dominant member of the shrub layer of the more mesic forests as well as the more xeric Montane Scrub Community of the middle to upper elevations. Its closest relatives are in the temperate deciduous forests of eastern North America and East Asia, giving it an anomalous distribution. Quercus sadleriana grows in soils with a wide range of pH and soil nutrients including low to high levels of magnesium, suggesting the possibility of serpentine races. The major form of reproduction appears to be vegetative by layering.

CHESTNUT OAKS

Chestnut oaks have been generally recognized but have not previously been formally defined in the taxonomic literature. The leaves very strongly resemble chestnut (Castanea) leaves having elliptic shape and dentate to shallowly lobed margins with regularly spaced secondary veins running through each tooth to the margin. These oaks comprise the North American series Prinoideae and Sadlerianae (Trelease, 1924; treated as subsection Sadlerianae by Camus, 1934-1954), and the Asiatic subsection Diversipilosae (Camus, 1934-1954). Included under the subheading chestnut oaks are five species in eastern North America and eight species in East Asia. It is not surprising that chestnut oaks are found both in East Asia and eastern North America considering the floristic similarities between these two regions. However, a paradox arises when we examine the forests of western North America, for there we find a shrub form of the chestnut oaks, Quercus sadleriana R. Br. Campst., in a considerably different forest type and climatic regime. What makes the western North American distribution more interesting is that Q. sadleriana occurs as a relict endemic in an area which Whittaker (1961) and others (Stebbins & Major, 1965; Wood, 1970; Wolfe, 1969) define as a major center of floristic diversity and endemism. The southern Appalachian region of eastern North America, from where most of the eastern North American chestnuts seem to emanate, is also known for these attributes.

The purpose of this paper is to (1) define the chestnut oaks, (2) give their salient characters, (3) discuss their distribution in general and give the distribution of Q. sadleriana in particular, and (4) discuss the ecology of the chestnut oaks and Q. sadleriana.

Definition of the Chestnut Oaks

The chestnut oaks have been defined as belonging to the section Quercus (white oaks) of the genus Quercus.[3] Three subsections in

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Associate Professor of Biology, Pacific Union College, Angwin, California

[3] Unpublished Doctoral Dissertation, G.J. Muth, 1976, The taxonomic and floristic relationships of Quercus sadleriana R. Br. Campst. to other chestnut oaks, University of California, Davis, California.

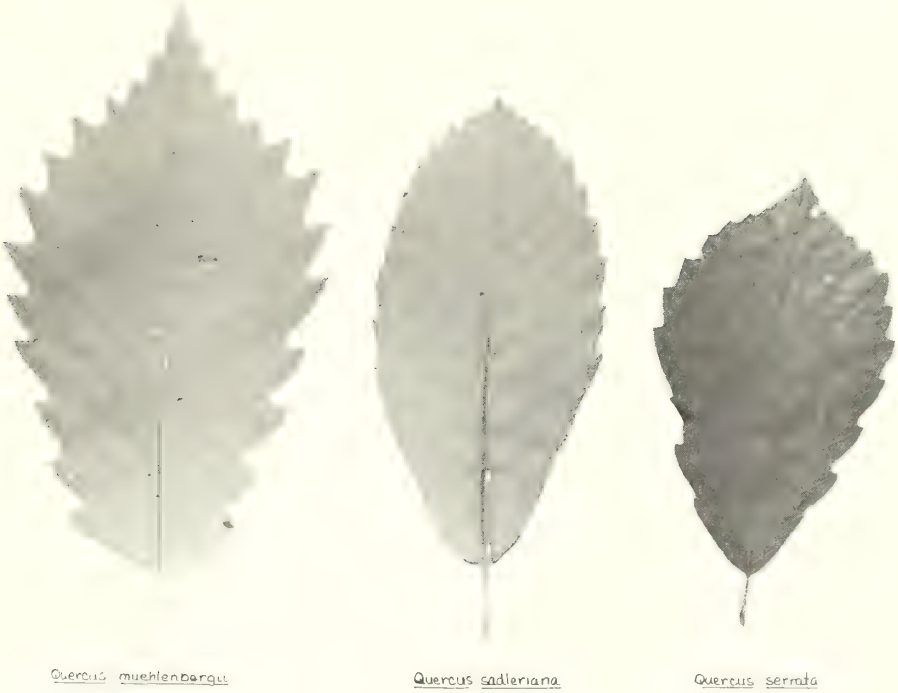

Figure 1-- Comparison of *Quercus sadleriana* with its two closest relatives.

section *Quercus* contain all of the chestnut oaks as follows (fig. 1):

A. Subsection *Diversipilosae* Schneider
  1. *Q. crispula* Blume, NE Asia, Japan, Korea
  2. *Q. serrata* Thunb., China, Japan, Korea
  3. *Q. griffithii* Hook. f. and Th., Bhutan, Burma, China, India, Laos, Sikkim
  4. *Q. malacothricha* A. Camus, China
  5. *Q. aliena* Bl., China, Japan, Korea
  6. *Q. mongolica* Fischer, China, Japan, Korea, S. Kuriles, Manchuria, Mongolia, Sakhalin, E. Siberia
  7. *Q. fabri* Hance, China, Korea
  8. *Q. liaotungensis* Koidz., China, Korea, Manchuria, Mongolia.

B. Subsection *Sadlerianae* Trelease
  1. *Q. sadleriana* R. Br. Campst., western North America.

C. Subsection *Prinoideae* Trelease
  1. *Q. bicolor* Willd., eastern North America
  2. *Q. prinus* L., eastern North America
  3. *Q. muehlenbergii* Engelm., eastern North America, New Mexico
  4. *Q. montana* Willd., eastern North America
  5. *Q. prinoides* Willd., eastern North America.

Characters Distinguishing Chestnut Oaks

The following is a list of the more salient external morphological features distinguishing the chestnut oaks:

1. Evergreen to deciduous leaves
2. Generally large leaves with mean widths of 3.2 inches and mean lengths of 6.4 inches
3. Cupule, generally rather large, approximately 0.2-0.8 inches in diameter
4. Leaves chestnut-shaped; more or less oval with a serrate to dentate margin
5. Teeth small to more or less deep, acuminate to obtuse, with or without small mucros at the tip of the teeth
6. Leaves with numerous, straight, unbranched secondary veins somewhat regularly spaced, at an angle of 45°-60° to the midvein, and extending to the apex of each tooth
7. Trichomes may or may not be present on the upper leaf surface, however, if they are present, they are generally quite sparse and simple or stellate or both
8. When mature, most species are trees. However, *Q. sadleriana* and *Q. prinoides* are both shrubs.

All species of chestnut oaks in North America occupy relatively mesic habitats. As far as I can determine, this is also the case for the eight East Asian species.

DISTRIBUTION OF *QUERCUS SADLERIANA*

As was previously indicated, *Diversipilosae* is generally distributed throughout eastern Asia, *Prinoideae* ranges through eastern North America, and *Sadlerianae* is located through northern California and southern Oregon. Maps showing the distribution of each of the chestnut oak species are in my doctoral dissertation.[3]

Quercus sadleriana occurs in Josephine, Curry, Douglas, and Coos counties of Oregon, and Humboldt, Trinity, Siskiyou, Shasta and Del Norte counties of California. The type locality is on the Crescent City Trail between Sailor's Diggings, Oregon, and Smith Creek, California. The elevational extremes are from 2000 to 7260 feet. The following information, from the accumulated data of 187 collections, shows these extremes:

A. Distribution extremes
    1. North---Wooden Rock Creek, near Agness, Coos County, Oregon, on the Bone Mountain Quadrangle, 42° 48' north latitude, 123° 55' west longitude
    2. South---Kerlin Creek, near Hyampom, Trinity County, California, in the Pilot Creek Quadrangle, 40° 36' north latitude, 123° 55' west longitude
    3. East----Sweetbrier Ridge, near Castella, Shasta County, California, Dunsmuir Quadrangle, 41° 4' north latitude, 122° 21' west longitude
    4. West----Snow Camp Mountain, near Gold Beach, Curry County, Oregon, Collier Butte Quadrangle, 42° 20' north latitude, 124° 9' west longitude.

B. Elevational extremes
    1. Highest---7260 feet, Preston Peak, near Happy Camp, Siskiyou County, Oregon, Preston Peak Quadrangle, 41° 50' north latitude, 123° 37' west longitude.

ECOLOGY OF *QUERCUS SADLERIANA*

The chestnut oaks are generally found in the temperate deciduous forests of Asia and North America that receive summer rainfall. The individual taxa of *Diversipilosae* and *Prinoideae* occupy a spectrum of habitats from relatively dry rocky conditions on limestone outcrops (*Q. aliena* and *Q. muehlenbergii*) to relatively mesic conditions (*Q. montana* and *Q. serrata*) to relatively wet lowland conditions (*Q. prinus*). No one species is found at all elevational levels but the group as a whole may be found at all elevational levels from timberline to wet lowlands at or near sea level. *Quercus sadleriana*, on the other hand, is distributed through an evergreen conifer forest under essentially summer-dry conditions. Comparing it with the range of habitats described for *Prinoideae* and *Diversipilosae*, *Q. sadleriana* inhabits the dry to mesic habitats in the middle to upper elevations. Siemens[4] and Kimbrough[5] both did ecological studies of the general area inhabited by *Q. sadleriana*. Siemens' work was an ecological analysis of the Preston Peak Area while Kimbrough compared the Montane Scrub Communities of the Trinity Alps, Marble Mountains and Preston Peak. *Quercus sadleriana* is a dominant member of the Montane Scrub Community on the more xeric south- and west-facing slopes and is dominant in the shrub layer of the more mesic Red Fir and Mixed Evergreen Forests. On the top of Preston Peak, it is a low shrub occupying somewhat protected areas.

On Preston Peak, where *Q. sadleriana* extends to its highest elevation, Siemens[4] recognized three major associations: Mixed Evergreen Association, Montane Forest Association and Subalpine Forest Association. He further subdivides them as follows:

A. Mixed Evergreen Forest Association
    1. 2085 to 3230 feet elevation
    2. Includes the following forest subtypes
        a. Black Oak Woodland
        b. Madrone-Tan Oak Woodland
        c. Douglas Fir Forest.

B. Montane Forest Association
    1. 3230-5375 feet elevation

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[4] Unpublished Masters Thesis, L.A. Siemens, 1972, A survey of the montane forest of the Preston Peak Study Area, Siskiyou County, California, Pacific Union College, Angwin, Calif.

[5] Unpublished Masters Thesis, D.J. Kimbrough, 1975, An ecological analysis of montane scrub in the Siskiyou Mountains, Trinity Alps, and Marble Mountains, Pacific Union College, Angwin, California.

2. Includes the following forest subtypes
    a. Douglas Fir
    b. Sugar Pine
    c. Ponderosa Pine
    d. Knobcone Pine
    e. Lodgepole Pine
    f. Port Orford Cedar.

C. Subalpine Forest Association
  1. 5735 feet and higher elevation in isolated stands on peaks and ridges
  2. Includes the following forest subtypes
    a. Noble Fir
    b. Weeping Spruce
    c. Mountain Hemlock
    d. Alaskan Yellow Cedar
    e. Jeffrey Pine-White Pine Woodland.

Siemens further indicates that the winters are long in this region with the first snows coming as early as September and lasting till as late as June or the first of July. All the significant precipitation comes during the winter with little or none during the summer.

He describes the topography as being rugged and steep. The direction of the slope generally determines the forest type. On the steepest upper slopes where soil does not collect, Alaskan yellow cedar (Chamaecyparis nootkatensis (D. Don) Spach.) is the only woody plant clinging to the rocks wherever it can find sufficient moisture.

Edaphically, this area contains many special areas such as acid bogs, seepages, etc. with small "islands" of relict and uncommon plants. Siemens includes Port Orford cedar (Chamaecyparis lawsoniana (A. Murr.) Parl.) and Alaskan yellow cedar among a number of species occurring in these relict populations.

According to Siemens, Q. sadleriana is a prominent member of the Sugar Pine Forest of the Montane Forest Association and of the Noble Fir and Weeping Spruce Forests of the Subalpine Forest Association. Quercus sadleriana appears in nearly all his transects except the Black Oak Woodland and Madrone-Tan Oak Forest of the Mixed Evergreen Forest Association. In addition to transect data, he did some soil analyses that included such factors as moisture, texture, color, pH, nitrates, calcium, phosphorus and magnesium on a total of 41 transects.

Number of Transects

With Q. sadleriana	32	
With soil moisture data.	17	dry
	5	moist
	2	wet
With soil texture data	23	rocky
	4	gravel
	1	deep humus
With soil color data	14	black
	12	yellow
	8	gray
	7	red

Soil Nutrients

pH	4.7	low
	5.2	mean
	5.7	high
Nitrates in ppm.	0.0	low
	1.0	mean
	8.0	high
Calcium in ppm	0.0	low
	527.0	mean
	2800.0	high
Phosphorus in ppm.	5.0	low
	36.0	mean
	100.0	high
Magnesium in number of transects	1	very high
	2	high
	2	medium
	6	low
	18	very low
	2	not present

Although Siemens doesn't recognize Montane Scrub in his study of the Preston Peak area, Kimbrough[5] sees this as a valid vegetation type along with the three types listed by Siemens. Thus, four vegetation types can be said to occur on Preston Peak: (1) Mixed Evergreen Forest, (2) Montane Forest, (3) Subalpine Forest and (4) Montane Scrub.

Kimbrough divides the Montane Scrub into three subtypes for the Preston Peak Area: "Typical" Montane Scrub, Woodland Scrub and Lowland Scrub. "Typical" Montane Scrub and Woodland both occur above 5200 feet as part of the Canadian Life Zone. Lowland Scrub occurs below 4300 feet in the Humid Transition Life Zone.

"Typical" Montane Scrub has four dominants in this area: greenleaf manzanita (Arctostaphylos patula Greene), huckleberry oak (Quercus vaccinifolia Kell.), deer oak (Quercus sadleriana R. Br. Campst.), and silk tassel bush (Garrya fremontii Torr.). Kimbrough indicates that it appears to be a successional stage to forest associations because of the broad ecotones between it and the forest associations maintained as a subclimax. This is due to lack of soil, soil moisture and soil build-up resulting from steepness of slopes and frequent fires.

Woodland Scrub is typified by Jeffrey pine (Pinus jeffreyi Grev. and Balf. in A. Murr.) and western white pine (Pinus monticola Dougl.) as major dominants with smaller amounts of incense cedar (Calocedrus decurrens (Torr.) Florin) and Douglas fir (Pseudotsuga menziesii (Mirb.) Franco.) in a very open woodland as the canopy layer. The greatest cover in this association is composed of a shrub layer of scrub species from the "Typical" Montane Scrub except for the subdominant pinemat manzanita (Arctostaphylos nevadensis Gray). This association is normally at elevations above 4850 feet and appears to be closely related to serpentine soils. Kimbrough feels that this community is climax on serpentine soils.

Lowland Scrub, occurring on the hillsides of the lower elevations, is associated with Mixed Evergreen Forest. Except for the dominant white-leaf manzanita (Arctostaphylos viscida Parry) and two incidental shrubs, buckbrush (Ceanothus cuneatus (Hook.) Nutt.) and red huckleberry (Vaccinium parvifolium Sm. in Rees.), the associates of this community are essentially the same as those of the "Typical" Montane Scrub.

The Preston Peak Montane Scrub patterns and those in the Trinity Alps are floristically similar except that greenleaf manzanita, huckleberry oak and sticky laurel (Ceanothus velutinus Dougl. ex Hook.) are the major dominants. Western service berry (Amelanchier pallida Greene) and pinemat manzanita,which occur as subdominants in the Preston Peak area, are dominants in the Trinity Alps. Quercus sadleriana, not being a member of the flora in the Trinity Alps, is not found in the Montane Scrub Association.

The Marble Mountain Montane Scrub dominants are greenleaf manzanita, huckleberry oak, sticky laurel, silk tassel bush (Garrya fremontii Torr.) and bitter cherry (Prunus emarginata (Dougl.) Walp.). These last two species are subdominants around Preston Peak and the Trinity Alps. Brewer's oak (Quercus garryana Dougl. var. breweri (Engelm. in Wats.) Jeps.) is dominant in the Marble Mountains, and subdominant on Preston Peak and the Trinity Alps, while Quercus sadleriana is dominant in the Marble Mountains and Preston Peak, and totally absent in the Trinity Alps.

In areas of relatively high abundance, it is difficult to distinguish between individual clones of Q. sadleriana, because the variation in many of the vegetative characters is very narrow from one clone to another. Although sexual reproduction seems to be good, with many acorns being produced, I am not aware of any significant studies documenting germination percentages and conditions for germination. I and my colleagues have, with great difficulty, tried to germinate acorns. Therefore, from the scanty evidence available, it appears that the major form of reproduction is by rhizomes and/or rooting at the nodes. I have personally observed node rooting in Q. sadleriana.

Summarizing the ecology of Q. sadleriana, it is possible to say that it occupies a spectrum of habitats from the cool, damp, moderately lighted forest shrub layer to the hot, dry, brilliantly lighted south slopes of the higher mountains. The soil in which it grows is usually rocky and generally black or yellow. The soil pH is always acid and occasionally very acidic while the nitrates are usually quite low with a substantial range of calcium (from 0-2800 ppm). The range of phosphorus as well as magnesium is also quite wide. It appears that Q. sadleriana is adapted to serpentine soils, with possibly even some serpentine races. By observation only, the major form of reproduction seems to be vegetative.

SUMMARY AND CONCLUSIONS

The chestnut oaks were defined as belonging to subsections Prinoideae, the five eastern North American chestnut oaks; Sadlerianae, the western North American chestnut oak, Quercus sadleriana R. Br. Campst.; and Diversipilosae the eight East Asian chestnut oaks. The three subsections are within the subgenus Leucobalanus, the white oaks. They typically have elliptic leaves with dentate to shallowly lobed margins showing regularly spaced secondary veins running out through each tooth to the margin, very strongly resembling Castanea leaves.

Quercus sadleriana is distributed through the Klamath Ranges of northern California and southern Oregon in Josephine, Curry, Douglas, Coos, Del Norte, Siskiyou, Humboldt, Trinity and Shasta counties. It occurs as a dominant member of the shrub layer in the more mesic forests under shaded conditions, as well as a dominant member of the Montane Scrub Community under dry and hot conditions. It is exposed to full sunlight on the southern slopes, and occasionally extends up into subalpine areas. It grows in a wide range of pH and soil nutrients including high to low levels of magnesium. The data reported by Siemens[4] shows Q. sadleriana growing on serpentine soils suggesting that there may be some serpentine races of this species. The majority of reproduction seems to be vegetative.

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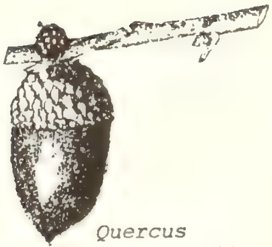

Quercus engelmannii

Change in Vegetative Cover of Oak Stands in Southern San Diego County: 1928-1970[1]

Carla R. Scheidlinger and Paul H. Zedler[2]

Abstract: The change in vegetative cover of thirty oak stands in southern San Diego County was estimated by comparing aerial photographs from 1928 and 1970. Point cover data showed a 13-percent decline in oak cover during the interval, with oak woodland declining at the expense of grassland and chaparral. Extrapolation of the 42-year transitions by use of Markov chain methods indicated a hypothetical equilibrium not far from present conditions. It is concluded that if the effects of land development are ignored, the cover of oak trees has not changed much in the last 50 years, but that this is not inconsistent with the view that many oak stands are senescent.

INTRODUCTION

There is good reason to suspect that the oak forests of Southern California are declining under the combined pressures of livestock grazing, recreational use, and urban and rural development (Hanes 1974, White 1966). But because oaks are long-lived trees, it is difficult to know just how rapid these changes are, and if the decline is general or confined to only a few stands. Aerial photographs are a potentially valuable source of information on rates of change in oak forests, and in this paper we report the results of a preliminary study using two sets of aerial photos to estimate change in the tree cover of thirty oak stands in southern San Diego County between 1928 and 1970.

In this paper we consider only changes in total tree cover, and not changes in stand perimeter. We also exclude those stands that were obviously disturbed by urban development or clearing in either 1928 or 1970. The changes we determine, then, do not include losses due to urban expansion; and represent what occurred in stands that remained in a more or less natural state for the 42-year period.

MATERIALS AND METHODS

Two sets of photographs from the Map Records Section in the Office of the San Diego County Engineer were used. The 1928 photographs were black and white vertical photographs of excellent quality at a scale of about 1:12500. The 1970 photographs, the only recent complete set available, are vertical aerial color photographs taken after the

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[1] Presented at the Symposium on the Ecology, Management and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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Kitchen Creek fire in 1970. These had a scale of about 1:33,333.

It was decided to restrict the area to be examined to the south central portion of San Diego County, a rough quadrangle bounded by El Cajon to the northwest, Pine Valley and Laguna Junction to the northeast, the Otay Reservoir to the southwest, and Cameron Corners on the southeast. The 1928 photographs covering this region were scanned for oak forests. Stands large enough to provide some sample hits were subjectively selected and located on USGS topographic maps. The same forests were then located on the 1970 photographs. Stands that had disappeared or been extensively altered by development between 1928 and 1970 were not considered.

Determination of the exact scale of each oak stand was made by use of permanent topographic or manmade features that could be located on both sets of photographs and on the USGS maps. Distance between two such points was measured on the USGS map, and calculations made to determine the actual ground distance spanned, and hence the scale of the two photos.

A proportional divider was used to mark off a straight row of eleven points or dots in a sheet of acetate, spaced to represent for each interval exactly 100 meters on the scale of the 1928 photograph. The first dot served as an intercept for a pencil line drawn on the acetate perpendicular to the line of the dots. When a ruler marked in increments of 0.5 mm was laid across the photograph, connecting two permanent topographic or man-made features, the dot line could be oriented over the photograph perpendicular to the ruler along the pencil line. Land cover type was recorded on data sheets for each dot along the line - a distance of 1 km in the photograph. The line was then moved along the ruler for the same distance that separated the dots on the acetate, and another ten points of land cover were recorded. This procedure continued for ten increments, or until well beyond the limits of the oak stand, whichever came first. This meant that most stands were sampled with 100 points, and all with at least 50 points.

The identical procedure, modified for differences in scale, was used to assess land cover of the same areas on 1970 photographs, which could be located by reference to permanent features. In this fashion, the same ground points could be evaluated for land cover in both 1928 and in 1970, and the same density of points, measured in actual ground distance, was used for both photos. Thirty oak stands were sampled giving a total of 2579 individual points.

The sampling amounted to a point method applied to photographs. The number of points which fell on each of eight cover types was recorded and a few of the smaller groups combined into the categories which are given in Tables 1 and 2 to give estimates of percent cover. We feel that the method is relatively accurate, and few ambiguities were encountered. However, it is clearly possible that small oak trees might be missed, especially when these occur in or near chaparral cover. It is also possible that some sycamores, willows, and cottonwoods might have been included in the oak category, especially in cases where these might have crowns contiguous with oaks. It was not possible to separate *Quercus agrifolia* (coast live oak) from *Quercus* engelmannii (Engelmann oak) and since both occur in the area surveyed, the oak category is a composite of these two species. However, *Q. agrifolia* is by far the more abundant species.

RESULTS

The overall results of the study are summarized in tabular form (table 1) where the combined data for all 30 stands and 2579 points are given. The total number of points recorded in each of the categories in 1928 and 1970 are in the final column and row of the table respectively. The remainder of the table is a transition matrix which gives the number of points which changed category or remained in the same between the two periods. The integer values along the diagonal, such as 152 for oak, represent the number of points

TABLE 1 COMBINED COVER DATA FOR ALL STANDS AND ALL CATEGORIES GIVING TOTALS IN THE LAST ROW AND LAST COLUMN AND THE NUMBERS OF POINTS THAT CHANGED CATEGORY OR REMAINED IN A CATEGORY IN THE REMAINDER OF THE TABLE THE UPPER VALUES IN EACH CELL ARE THE ABSOLUTE NUMBER OF POINTS, AND THE LOWER NUMBER THE PROPORTIONS FOR FURTHER EXPLANATION, SEE THE TEXT

CLASSIFICATION IN 1970

CLASSIFICATION IN 1928	OAK	GRASS	CHAPARRAL	ROCK	STREAM	DEVELOPED	1928 TOTAL
OAK	152 3535	92 2140	156 3628	11 0256	2 0017	17 0395	430 1667
GRASS	75 1875	173 4325	109 2725	9 0225	1 0025	33 0825	400 1551
CHAPARRAL	132 0926	161 1129	1052 7377	43 0302	3 0021	35 0245	1426 5529
ROCK	4 0146	7 0255	37 1351	221 8067	1 0036	4 0146	274 1062
STREAM	4 3636	2 1818	2 1818	1 0909	2 1818	0 0000	11 0043
DEVELOPED	6 1579	14 3684	4 1053	0 0000	0 0000	14 3684	38 0147
1970 TOTAL	373 1446	449 1741	1360 5273	285 1105	9 0035	103 0399	2579

which did not change classification, while the off-diagonal elements, such as the 75 for grass to oak and 92 for oak to grass, represent the number of points which changed categories. These values are interpreted by remembering that the row categories represent the 1928 state, and the column categories the 1970 state. Thus 75 grass points in the 1928 photos became oak points in the 1970 photos, while 92 oak points in the 1928 photos became grass points in the 1970 photos.

The fractional values in italics beneath the numbers in the last column and last row represent the proportion of each category present in 1928 and 1970 respectively, while the italicized fractional values in the remainder of the table are the proportions of the 1928 stands that changed, or did not change, to another category. These proportions, which sum to one across the row, may be taken as estimates of the probability of a transition from one state to another. Thus 21 percent of the 430 1928 oak points became grass points.

The rock category gives an estimate of the reproducibility of the sample points. Since the rocks which were recorded were mostly relatively large, a perfectly accurate placement of points would lead to little change in the proportion of rock cover, and most points recorded in this category in 1928 would remain in that category, excluding those cases where the crowns of trees or large shrubs might overgrow them. Thus the majority of the 274 points recorded as rock in 1928 should remain as rock, which is verified by noting that there are 221 points in the rock - rock category, indicating that 81 percent of the points did not change, and that therefore there is an acceptable margin of error in the relocation of points. While the ideal would be exact relocation of points, there is no reason to suppose that minor displacements would lead to significant biases in estimating change in cover of the various cover types.

From table 2 we can see that there has been, overall, a statistically significant but not drastic decline in the abundance of oaks, from 4.30 Km^2 to 3.73 Km^2 over the entire area surveyed. At the same time, grass and developed areas increased slightly, while chaparral also showed a slight decrease. These data, as well as the subjective impressions gained from the photos seem to indicate that oak forests are becoming more open and losing out to grass, which would be expected if decline was a result of failure of reproduction within stands rather than encroachment by chaparral. An additional factor that probably contributed to the observed decline of oaks is fire. The 1970 set of photographs, the only complete set available for the area, had been made shortly following a fire, the range of which had encompassed many of the stands surveyed. This fact did not affect the accuracy of the ground cover estimates, but a cursory review of photographs taken from 1 to 6 years previous to the burn suggested that there had been some loss of cover attributable to the fire.

TABLE 2. AREA IN SQUARE KILOMETERS OF LAND COVER TYPE, AND PERCENT CHANGE OF EACH TYPE FROM 1928 TO 1970. CHANGES WITH AN ASTERISK ARE SIGNIFICANT WITH $P<0.05$ USING THE NORMAL APPROXIMATION TO TEST FOR DIFFERENCES IN PROPORTIONS

	OAK	GRASS	CHAPARRAL	ROCK	DEVELOPED
AREA IN 1928	4.30	4.00	14.3	2.74	0.38
AREA IN 1970	3.73	4.49	13.6	2.85	1.03
PERCENT CHANGE	-13.3*	+12.3	-4.6	+4.0	+171.1*

The same data can be expressed on an area basis, to give a better feeling for the sample sizes and the areas involved. In table 2 the decline in oak cover is estimated to be 13.13 percent while grass increased by 12.3 percent, these changes all expressed relative to the cover in 1928. Not surprisingly, the largest percentage change was in the developed area, which increased by over 17 percent.

While the evidence is against any catastrophic decline, it is sufficiently large to justify concern over the future of the oak forests. In interpreting our data, it must be remembered that individual tree size was not measured, and it is an important piece of information in interpreting rates of decline. On the one hand, a woodland with a lower cover in 1970 than in 1928 might nevertheless be on the increase if in the interim fewer large trees were replaced with a larger number of small vigorous trees. On the other hand, a forest which in 1970 showed an increase in coverage might nonetheless still be on a downward trend if the increase in cover was due solely to the increase in crown cover of old trees with no new trees having become established. A more detailed examination of the photos could provide some quantitative information to characterize better the nature of the change, but it is our subjective opinion that the declines are a combination of a loss both of cover and of individuals, and may indicate a long term but gradual downward trend which may accelerate as the large old trees which seem to be the most abundant individuals in many oak forests begin to die off.

To this point, we have considered only the overall summary which combined all data points for all 30 oak stands. A somewhat different perspective is given by looking at the degree of decline on an individual stand basis. In figure 1 the percent of cover of oaks lost or gained between 1928 and 1970 is plotted against the area of the oak stands in square kilometers. In addition, the stands are classified into three types - savannah, where the oaks were dotted fairly sparsely across chaparral or grassland; woodland, where the oaks presented a dense, more or less unbroken, canopy to the aerial view; and riparian strips, in which dense narrow bands of oaks lined the sides of a streambed.

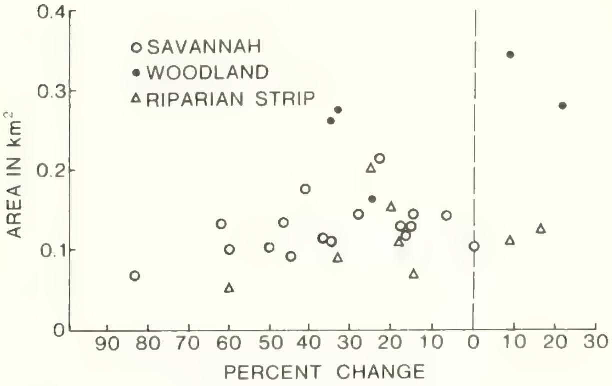

Figure 1--Percent change in oak cover between 1928 and 1970, plotted against the area of the stands in 1928. See text for a definition of terms used.

It is clear from figure 1 that the decline in oak forests is not general, since four out of thirty forests showed increases. As mentioned above, this does not necessarily mean that these stands are "recovering" since the increase in cover could be merely due to established trees become larger. Most of the stands, though, are on the negative side, with one third of the stands showing a loss of one third or more of their 1928 cover value. For the graph as a whole, there is a hint of a correlation between the total cover of the woodlands in 1928 and their degree of decline, with the smaller stands tending to show greater decline. While plausible explanations for this pattern might be suggested, we feel that more data are necessary before firm conclusions can be drawn. This is especially true because the 1970 photos include the effects of the Laguna fire.

We pointed out earlier that the data in the body of table 1, excluding the last row and column, could be taken as estimates of the probability that a point in one of the categories will transform to any of the other categories in the 42 year period. Thus the probability that an oak point on the 1928 photos will be recorded as a grass in the 1970 photos is estimated at .21 while the probability that a grass point will be recorded as an oak point is .19.

If the assumption is made that the probabilities of transition will be the same for all 42-year periods in the future; that is, if they are held constant, the matrix may be used to project the future proportions of cover types. This is a simple application of Markov chains which was suggested by Anderson (1966) and which has been used by Stephens and Waggoner (1970). The particular matrix of probabilities obtained here predicts that an equilibrium will eventually be reached, and in accordance with the properties of Markov chains, this equilibrium is independent of the initial conditions. The predicted equilibrium proportions are:

Oak	Grass	Chaparral	Rock	Stream	Developed
.14	.19	.49	.12	<.01	.05

At the hypothetical stable point oak is close to the observed 1970 value, grassland is somewhat higher, chaparral lower, and developed land considerably increased. This would seem to indicate that a continuation of the present trends will lead to relatively little change from the present state of the oak forests. But it is of course debatable if present trends will hold, and the projection must be taken only as an indication that there is nothing in our numerical results that would predict a drastic decline.

DISCUSSION

Since very few field studies have been conducted on the oak communities in southern California, our interpretations can only be compared to work done in the northern or central parts of the state (Sampson 144, and White 1966). The general overall losses of both chaparral and oak to grass are not too surprising, especially in areas where livestock grazing or browsing by deer is heavy. Sampson (1944) reported that grassland is favored in areas where chaparral is experiencing a general decadence following a long fire-free period. The conclusion that oak declines are a combination of loss both of cover and of individuals is consistent with White's (1966) observation that grazing can severely restrict recruitment of new individuals due to failure of seedlings to successfully establish. The generally favorable showing of denser woodlands in Figure 1 echoes Griffin's (1977) reports that oaks may be increasing in density but not in range.

There are good reasons to suppose that oak woodlands are declining, and yet we did not find a very large decrease between 1928 and 1970. Moreover a large part of the change observed may be the result of the 1970 fire, and it seems likely that the same analysis, using photos taken either just before the 1970 fire or long enough after it to include the recovery of crowns, would indicate an even smaller negative change. While our study seems to show that the decline in oaks is not critical, it does not allow us to conclude that there is no problem. More detailed studies are needed to determine if the gross trends we observed indicate a stable population of oaks or an accumulation of large but senescent individuals.

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Canyon Live Oak Vegetation in the Sierra Nevada[1]

Rodney G. Myatt [2]

Abstract: In the northern Sierra Nevada, data from stand surveys were used to categorize the phases in the canyon live oak (Quercus chrysolepis) dominated oak-hardwood forest and relate them to the environmental gradients of soil moisture and elevation. The soil moisture gradient was determined primarily from indicator species. Canyon live oak is the major species bridging the Foothill Woodland, Mixed Conifer and Mixed Evergreen associations. The overlapping nature of canyon live oak vegetation is an important factor in the species' morphological variation.

INTRODUCTION

Canyon live oak (Quercus chrysolepis) is considered one of the most variable, ecologically and morphologically, of the California oaks (Jepson 1925, Munz and Keck 1959, Myatt 1975). It is certainly the most widespread (Griffin and Critchfield 1972). Its many common names reflect also the diversity of outlooks botanists and laymen have had with the species: canyon live oak, maul oak, gold-cup oak, laurel oak, pin oak, mountain live oak, white live oak, hickory oak, and drooping live oak.

Canyon live oak occurs in the general assemblage of vegetation types occupying the zone between the oak woodlands and the montane forests. This makes it a central member of the Mixed Evergreen forests of the north coastal region and the related oak-hardwood forests of the Sierra Nevada and southern California (Sawyer, Thornburgh, and Griffin 1977, Griffin 1977, Whittaker 1960). These associations, especially the Mixed Evergreen, represent a highly variable vegetation with a long history of transitional relationships between elements of the Arcto-Tertiary and Madro-Tertiary Geofloras and their derivatives (Axelrod 1958, 1959, 1977, Raven and Axelrod 1978, Whittaker 1961).

Because of its widespread geographic distribution and elevational range, canyon live oak overlaps into a number of climatic zones, vegetation types, and floristic regions. It occurs in twelve of the seventeen forest communities described by Munz and Keck (1949, 1959). Within a given region, the terrain associated with mountains and canyons results in a close juxtaposition of varying slopes, aspects, soils, and microclimates. The passage of rivers through several zones and the climatic vagaries of canyons contribute to the opportunity for such species as canyon live oak to occur in many habitats.

The purpose of this study was to categorize the community types and phases in which canyon live oak occurs within one region, the northern Sierra Nevada, and to relate these to the major environmental gradients, namely soil moisture and elevation (temperature).

STAND SURVEYS

The northern portion traversed by the Yuba River has a relatively high annual precipitation of about 60 inches (1500+ mm) and a well developed oak-hardwood association equivalent to the Mixed Evergreen. The Stanislaus River region to south has less precipitation, 40+ inches (1100 mm) and lacks many of the Mixed Evergreen constituents. Douglas-Fir (*Pseudotsuga menziesii*) and madrone (*Arbutus menziesii*) are only occasionally found together here.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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Forty-one stands were sampled and data obtained on species composition, abundance, cover and habitat characteristics (table 1, figure 1). The stands were subsequently grouped into eight vegetation classes, based primarily on the woody perennials. The stands' placement along a soil moisture gradient was determined by calculating the Vegetation Moisture Index (VMI) for each stand. This is done by compiling a list of indicator species of known soil moisture preferences. Each indicator species is assigned to a soil moisture class, with its respective Drought Index number. The VMI for a stand is the mean of the Drought Index numbers of the indicator species present. The list of indicator species was taken primarily from work by Griffin (1967) and Waring (1969, Waring and Major 1964), with some species from my own data. Soil moisture conditions were also determined for a few sites by measuring the pre-dawn xylem sap tensions of canyon live oak specimens during late summer. A pressure chamber (Schollander bomb) was used for this.

VEGETATION TYPES

I have recognized eight phases, or dominance types, of canyon live oak vegetation, based on the relative abundance of the major woody species. These represent recognizable units in the transitions between the three basic vegetation types. They are described as follows:

Oak Woodland

I. Oak - Digger Pine (*Q. wislizenii* - *Q. douglasii* - *P. sabiniana*).

This is the Foothill Woodland of most classifications, especially the interior live oak phase (Griffin 1977). Canyon live oak is only an occasional associate on north-facing slopes of ravines.

II. Mixed Live Oak Woodland (*Q. wislizenii* - *Q. chrysolepis*).

This is a slightly more closed woodland than "I", tending towards forest. Both live oaks occur on steeper slopes within the Foothill Woodland where blue oak is absent. There is a prominent understory of shrubs: *Rhus* (*Toxicodendron*), *Arctostaphylos*, *Heteromeles*.

Mixed Evergreen

III. Mixed Oak Forest (*Q. wislizenii* - *Q. chrysolepis* - *Q. kelloggii*).

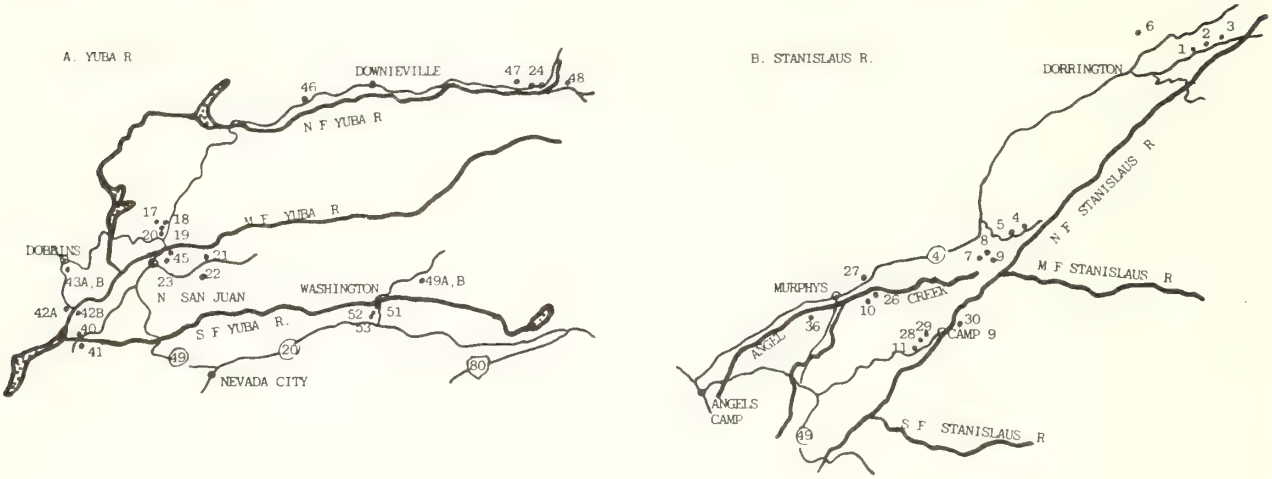
This occurs on north-facing slopes and extends into riparian forests along summer-wet creeks through the upper Mixed Oak Woodland. It is more mesic than "II", with *Acer*, *Vitis*, and *Umbellularia*. It grades into Foothill Woodland on south-facing slopes and Oak-Pine on the north-facing and upper slopes.

Table 1--Stands and data from the Yuba River and Stanislaus River regions, Sierra Nevada

Stand	Elev. m.	Slope °	Asp.	Vegetation	Type	VMI
(Yuba)						
40	245	23°	S	Oak Woodl.	I	7.0
41	245	27	N	Mix Oak F.	III	5.9
42A	350	30	S	Oak Woodl.	I	6.4
42B	350	30	N	Mix Oak F.	III	5.5
43	550	5-30	N-S	Oak-Evrgn.	IV	4.8
44	600	36	WSW	Oak-Evrgn.	IV	5.0
45	640	35	N	Mix Evrgn.	V	4.3
17	640	25	SE	Oak-Evrgn.	IV	5.2
18	610	25	SE	Oak-Evrgn.	IV	5.5
19	610	33	ESE	Oak-Evrgn.	IV	5.1
20	610	35	SE	Mix Oak W.	II	5.1
21	850	5	N-S	Mix Conif.	VIII	5.0
22	850	5-10	S	Oak Woodl.	I	6.1
23	700	25	N	Mix Evrgn.	V	4.4
46	900	35	S	Canyon Oak	VI	4.7
47	1200	30	S	Oak-Conif.	VII	5.3
24A	1250	20	S	Canyon Oak	VI	4.7
24B	1250	15	S	Mix Conif.	VIII	4.9
48	1210	5-20	S-E	Mix Conif.	VIII	---
49A	1100	38	S	Canyon Oak	VI	4.8
49B	1100	30	W	Mix Conif.	VIII	4.1
51	1000	40	ENE	Mix Conif.	VIII	4.4
(Stanislaus)						
11	365	25	ENE	Mix Oak W.	II	6.5
28	335	35	SE	Oak Woodl.	I	7.4
29	335	30	NE	Mix Oak W.	II	7.0
30	330	30	NW	Mix Oak F.	III	6.35
36	610	30	N	Mix Oak F.	III	5.7
10	670	32	WNW	Canyon Oak	VI	6.4
26	670	30	W	Mix Oak F.	III	5.25
27	670	30	SE	Mix Oak W.	II	5.8
7	950	10	N	Oak-Conif.	VII	5.5
8	910	30	N	Oak-Conif.	VII	5.4
9A	760	37	NE	Oak-Conif.	VII	5.9
9B	700	40	NE	Canyon Oak	VI	7.7
5	850	33	E	Oak-Conif.	VII	5.9
4	730	30	E	Oak-Evrgn.	IV	6.3
6	1600	18	SE	Mix Conif.	VIII	5.0
1	1400	30	SE	Oak-Conif.	VII	4.6
2	1400	40	SE	Canyon Oak	VI	5.25
3	1350	35	ESE	Canyon Oak	VI	5.25
58	370	15	N-S	Oak-Evrgn.	IV	5.2

IV. Mixed Oak - Evergreen Forest (*Q. chrysolepis* - *Q. kelloggii* - *P. ponderosa* - *Pseudotsuga menziesii*).

Figure 1-- Locations of stands in the Yuba River (A) and Stanislaus River (B) regions.



This type occurs on all slopes at mid-to-lower elevations in more mesic climates, above the Oak Woodland. It includes *Arbutus*, *Aesculus*, *Calocedrus*, and *Rhus diversiloba*. It is the more xeric phase of the Mixed Evergreen Association and consists of two subphases itself: 1) *Quercus chrysolepis* - *Umbellularia* on steep slopes within the Mixed Evergreen and 2) *Q. kelloggii* - *Arbutus* on the flatter, south-facing slopes in the Yuba River region and on north-facing slopes in parts of the Stanislaus River region.

V. Mixed Conifer - Evergreen Forest (*Pseudotsuga menziesii* - *Q. kelloggii* - *P. ponderosa* - *Q. chrysolepis*).

This occurs along north-facing slopes opposite and along creeks and draws through "IV". There usually are more shrubs and less herbs, and includes *Acer*, *Cornus*, *Corylus*, and *Calycanthus*.

Types IV and V make up the typical Mixed Evergreen Forest and represent the two ends of the hardwood to conifer phases. Neither type is represented well in the Stanislaus River region. In the Yuba River region a *Lithocarpus* - *Arbutus*-*Pseudotsuga* phase occurs, lacking canyon live oak.

VI. Canyon Live Oak Forest (*Q. chrysolepis*

Canyon live oak groves and small forests occur within the Mixed Conifer zone especially. There are few associates, but usually some *R. diversiloba* and *Polystichum munitum*. This type occurs also as depauperate patches of oak-hardwood forest on rocky points and steep slopes within the Yuba River region.

Mixed Conifer

VII. Mixed Oak - Conifer Forest (*Q. chrysolepis* - *Q. kelloggii*).

This occurs as groves of mixed oak forest within the Mixed Conifer zone. It usually occurs on southerly exposures or less favorable sites than the conifer forest, and represents a phase between the canyon live oak and the conifer forests.

VIII. Mixed Conifer - Oak Forest (*P. ponderosa* - *Ps. menziesii* - *Q. kelloggii* - *Q. chrysolepis*).

Canyon live oak overlaps into the Mixed Conifer Forest as an understory element. Also included are *Abies*, *Calocedrus*, *P. lambertiana*, *Ceanothus*, *Arctostaphylos*, and *Chamabatia*. *Pseudotsuga* is less common in the Stanislaus River region. In the Yuba River region it is more prominent on north-facing slopes and ridges above the canyon live oak.

In the above vegetation types, canyon live oak occurs in its typical tree form. In addition it may occur in chaparral vegetation as a result of being able to stump-sprout and exist as a shrub and also to hybridize with the shrubby huckleberry oak (*Q. vaccinifolia*).

MOISTURE GRADIENT

The above placement of stands into dominance types roughly relates to their placement along a moisture gradient. A temperature gradient and varying soil conditions also enter in, owing to the elevational, topographic, and edaphic changes within the regions. Certain species are well known as indicators of given moisture or other habitat conditions. Using the Drought Index groups and indicator species as compiled by Griffin and Waring, I listed those which are associated with canyon live oak in one place or another (table 2). Not all of these, however, were present in the stands that I surveyed here, at least at the time. The starred (*,**) species are those that were used in computing the Vegetation Moisture Index for the stands I surveyed. The double starred (**) are those not on the lists of Griffin and Waring, but added here based on their close associations with the other species. In table 1 can be found the Vegetation Moisture Index (VMI) for each stand.

The stands were then graphed with the VMI plotted against the elevation (fig. 2). Stand 58, taken at Pine Grove, Amador County, is slightly to the north of the Stanislaus River region stands and is included here as a point of reference. It is the only stand sampled near the Stanislaus River with some semblance of a Mixed Evergreen Forest.

VEGETATIONAL RELATIONSHIPS

The general slope of the stand arrangement is positive (fig. 2) since the elevation gradient corresponds to a moisture gradient. The arrangement of the stands, particularly those in the Yuba River region, appear as a somewhat elongated triangle, with the Foothill Woodland in the lower left corner, the Mixed Evergreen in the lower right, and the Mixed Conifer in the upper right. Stands of predominantly canyon live oak (VI) seem out of place in a simple moisture gradient and instead represent phases of the major types in which other factors are important, such as steepness of slope, soil depth, and rockiness. Such stands occur mainly at the higher elevations within the Mixed Conifer zone where slope, aspect, and soil depth differences can result in marked contrasts in habitats. Thus separation of the more tolerant canyon oak from the conifers and black oak is possible. Within the Mixed Evergreen zone, particularly near the Yuba River, there is apparently enough moisture to support a number of associates on most sites where canyon oak can occur.

Table 2-- Soil moisture indicator species found occurring with canyon live oak and their respective Vegetation Drought Index groups (DI)

DI	Species
I	Taxus brevifolia
II	Acer macrophyllum**
	Chrysolepis sempervirens
	Calycanthus occidentalis**
	Smilacina racemosa
III	Abies concolor*
	Cornus nuttallii*
	Galium triflorum
	Corylus cornuta californica**
	Lithocarpus densiflorus**
IV	Arbutus menziesii**
	Ceanothus integerrimus*
	Berberis piperiana
	Carex rossii
	Festuca occidentalis
	Pinus lambertiana*
	Pseudotsuga menziesii*
	Ribes roezlii
	Rosa gymnocarpa*
	Symphoricarpos acutus*
	Trientalis latifolia*
V	Arctostaphylos patula
	Bromus orcuttianus
	Calocedrus decurrens*
	Ceanothus prostratus
	Chamabatia foliolosa**
	Hieracium albiflorum
	Melica aristata
	P. ponderosa*
	Polygala cornuta*
	Pteridium aquilinum*
	Rhamnus rubra**
	Sitanium hystrix
	Viola lobata
VI	Amelanchier pallida*
	Arctostaphylos manzanita
	A. viscida*
	Castileja applegatei
	Clarkia rhomboidea
	Collomia grandiflora
	Comandra pallida
	Galium bolanderi
	Lathryus sulphureus
	Pedicularis densiflora
	Prunus subcordata
	Quercus garryana
	Q. kelloggii*
	Sanicula bipinnata
	Stipa lemmonii
	Wyethia mollis
VII	Agoseris retrosa
	Arabis holboelii
	Brodiaea multiflora
	Ceanothus cuneatus*
	C. lemmonii
	Cercis occidentalis*
	Cercocarpus betuloides*
	Collinsia parviflora
	Dodecatheon hendersonii
	Eriophyllum lanatum*
	Lonicera interrupta*
	Purshia tridentata
	Q. wislizenii**
	Ranunculus occidentalis
	Rhamnus californica*
	Rhus diversiloba*
VIII	Bromus tectorum
	Penstemon deustus
IX	Adenostema fasciculatum**
	Pinus sabiniana**
	Q. douglasii**

Figure 2-- Relationships of stands to elevation and Vegetation Moisture Index.

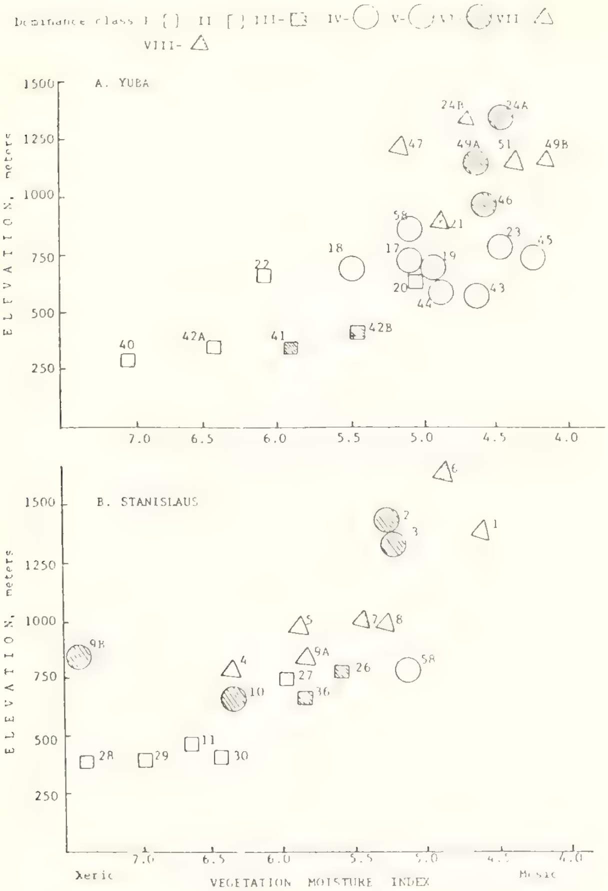
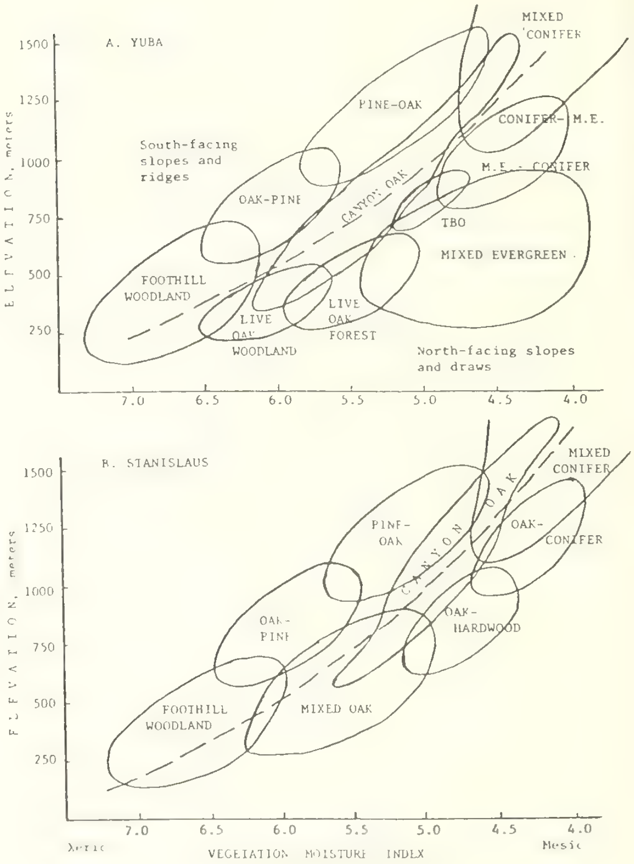


Figure 3-- Vegetation relationships in the Yuba River and Stanislaus River regions.



From the plotting of stands in figure 2, and from other observations, I have come up with a graphical representation of the relationships of canyon live oak vegetation in the northern Sierra Nevada (fig. 3). The dashed line in the middle of each graphically represents the canyon slopes near the river, excluding the strictly riparian vegetation. To the right are the north-facing slopes and relatively more mesic habitats. To the left are the exposed ridges and south-facing slopes. The limits of the vegetation groups are of course arbitrary, reflecting the gradual transitions.

The three basic vegetation types are shown, with the Mixed Evergreen considerably shrunk or eliminated in the Stanislaus River region. Canyon live oak generally occupies intermediate associations between the three basic types and is the primary species bridging all three.

The Live Oak Woodland and Live Oak Forest are combined in the Stanislaus graph. The oak forests have become mostly canyon oak forests.

Even with its broad distribution throughout several communities, the compensation of moisture related factors results in a relative site constancy for canyon live oak with regard to the moisture gradient. Most of the measures of minimum xylem sap tensions were similar (-5 to -10 atm) and indicative of root systems probably reaching ground water. Some higher stresses (to -22 atm) from some exposed xeric sites also indicate some amount of variability here and may account for the species' abilities to intrude into chaparral habitats within the forest. Likewise, its noted tolerance for poor soils (e.g. serpentine) and infrequent burning has apparently resulted in its prominence in such azonal habitats where there is less competition from the faster growing conifers and other hardwoods. There seems to be a relationship between widespread adaptability and lack of competitiveness, where a species is either able to utilize many habitats to some extent or to utilize one or a few effectively (Solbrig 1970).

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Lithocarpus densiflorus

Inventory and Quantification of Central Coast Hardwood Resources in California[1]

Norman H. Pillsbury[2]

Abstract: A method for determining the volume and weight of standing hardwood trees has been developed and tested. Cubic volume and weight tables have been developed for coast live oak (*Quercus agrifolia* Née), blue oak (*Quercus douglasii* Hook. and Arn.), valley oak (*Quercus lobata* Née) and tanoak [*Lithocarpus densiflorus* (Hook. and Arn.) Rehd.]. Diameter at breast height and total tree height provided the best relationship for determining tree volume and weight. Hardwood stand characteristics are presented for volume, weight, basal area, and number of trees. Three stand density classes are defined by class average and range of values for volume, weight, and basal area. Current and future studies include the development of hardwood photo volume and weight tables, preparation of maps showing volume and weight distributions, and evaluation of growth, regeneration, and thinning data.

INTRODUCTION

Until recently a cubic foot volume or total fibre inventory of the central California hardwood species was not available to property owners or resource agencies responsible for their management. Consequently the Forestry Committee, Central Coast Resource Conservation and Development Area[3] (CCRC&D), assisted by the California Department of Forestry, Soil Conservation Service, and U.S. Forest Service has sponsored this study to inventory and evaluate the hardwood resources in the Central Coast counties, California (fig. 1). Also, the Renewable Resources Evaluation Research Unit, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon is planning to include a hardwood inventory as part of the next forest resource assessment for the State of California.[4]

As a commodity, hardwoods in central California are used mostly for fireplace fuel and seldom for other wood products. As other forms of energy decrease in availability and increase in cost, the use of these renewable hardwoods for fuel in power plants and fireplaces becomes more attractive and practical. As an amenity, hardwoods are recognized for recreation, esthetics, and watershed protection in the woodland environment, while shade and visual enhancement are important in the urban setting. Native hardwoods are often ignored or viewed as a nuisance. This opinion, although rapidly changing in many areas, is still shared by some landowners who prefer converting woodland to rangeland or agricultural fields.

The objectives of the study (fig. 2) are to provide property owners and resource managers with a method for estimating volume and weight for individual trees, small stands of trees, and large tracts of woodlands. Eventually, guidelines will be developed for regeneration and planting of hardwoods and for stand improvement and protection. The opportunity for local citizens to manage and market hardwood products through an oak-woodland cooperative will be explored. Species under study are coast live oak

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Associate Professor, Natural Resources Management Department, California Polytechnic State University, San Luis Obispo.

[3] The Central Coast Resource Conservation and Development Area is composed of Resource Conservation Districts from the following Central Coast Counties: Santa Cruz, Monterey, San Benito, and San Luis Obispo, California.

[4] Personal Communication, 1979, Charles Bolsinger, Renewable Resources Evaluation Research Unit, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

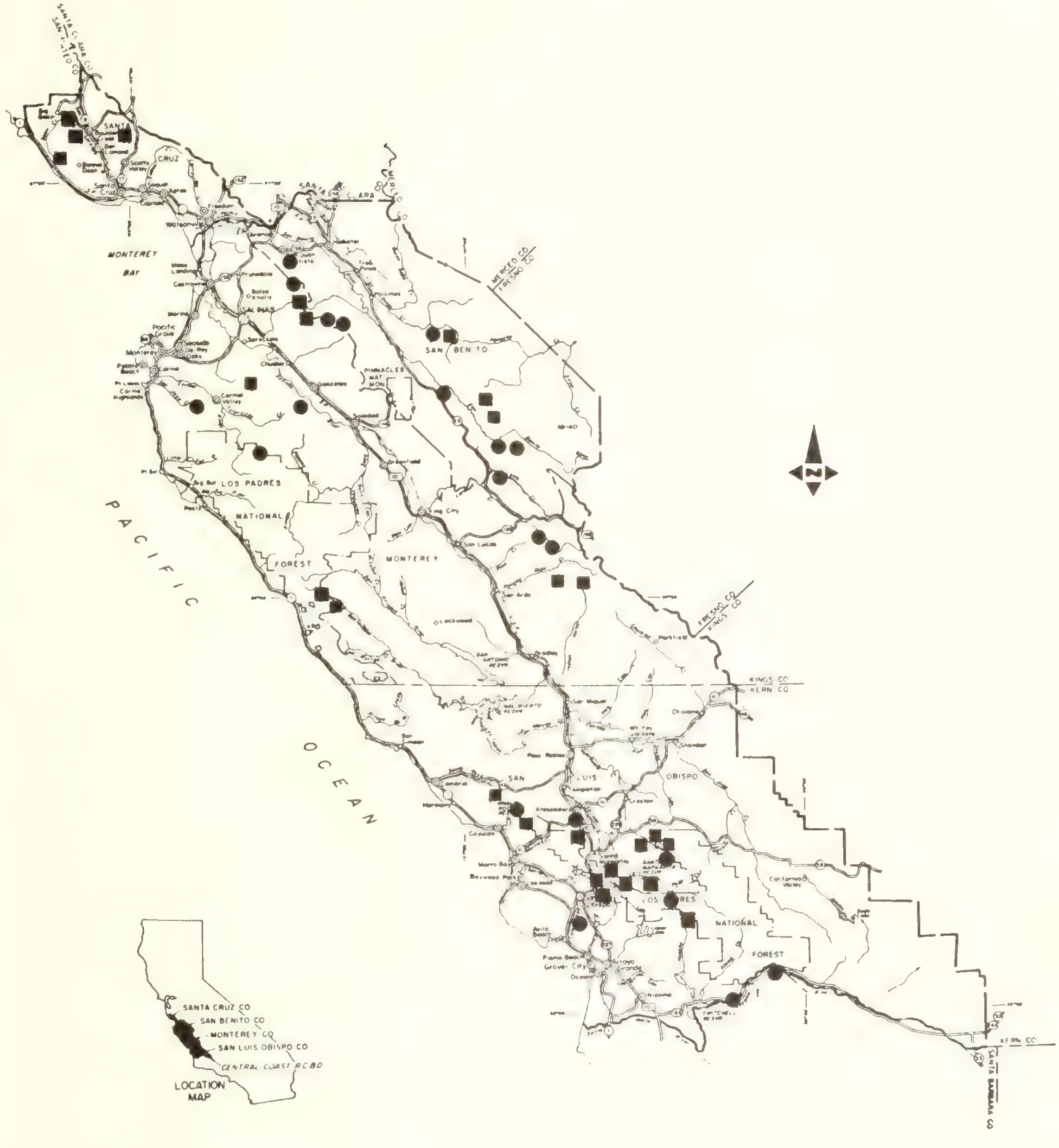

Figure 1--Sample plot locations in central coast counties, California. Squares are field plots, circles are photo plots.

PHASE I	PHASE II	PHASE III	PHASE IV	PHASE V
A. Feasibility study. Development of technique for a) Volume and density measurement methodology Status: Completed Report submitted: February 1978	A. Construct hardwood volume and weight tables for the Central Coast counties. Status: Completed Report published: April 1978	A. Develop photo-volume tables for Central Coast counties. Status: In progress Completion date: Summer 1979	A. Determine hardwood site index and yield data for plots in the Central Coast counties. Status: Proposed Duration: 1-2 years	A. To conduct a pulpwood and firewood market study for existing hardwoods in the Central Coast. Status: Conceptual Duration:
	B. Determine hardwood stand density characteristics for the Central Coast counties. Status: Completed Report published: July 1978	B. Construct fuel inventory maps for Central Coast counties. Status: In progress Completion date: Summer 1980	B. Develop guidelines for regeneration stand improvements, protection, and rotation. Status: Conceptual Duration:	B. Development of an oak-woodland cooperative. Status: Conceptual Duration:

Figure 2. Schedule for the inventory and quantification of Central Coast woodland resources in California.

(*Quercus agrifolia* Née), blue oak (*Quercus douglasii* Hook. and Arn.), valley oak (*Quercus lobata* Née), tanoak [*Lithocarpus densiflorus* (Hook. and Arn.) Rehd.], interior live oak (*Quercus wislizenii* A. DC.), and Pacific madrone (*Arbutus menziesii* Pursh).

The results from this study should aid woodland owners to objectively manage their land for hardwood products or for esthetics and other uses. The manager will now have a better information base from which to make his decisions.

METHODS AND RESULTS OF COMPLETED STUDIES

Hardwood Volume Tables

The hardwood species of the Central Coast tend to be characterized by rather short boles and branchy crowns. The number of segments and the complexity of the branching network makes volume measurement of hardwoods both difficult and time consuming. Measuring tree volume after a tree has been cut gives reliable data but is very time consuming. Consequently, an indirect procedure is needed that allows accurate measurements of the volumes of standing trees. This, of course, needs checking by direct measurement of fallen trees.

The problem of accurately measuring the volume of standing trees was solved as follows. Indirect measurements were obtained on standing trees with a Spiegel relascope (fig. 3); any equivalent upper stem dendrometer can be used. Each tree was divided into "stem and branch" segments (minimum diameter to 4 inches) and "terminal" segments. End diameters and the length of each stem and branch segment were measured and the volume was calculated from Smalian's formula (Husch *et al* 1972) as follows:

$$\text{Segment volume} = [(h/2)(A_b + A_u)] \text{ where}$$

A_b is the cross-sectional area at the large end of the segment
A_u is the cross-sectional area at the small end of each segment, and
h is the segment length.

The lengths of terminal segments 4 inches (10 cm) in diameter (at the large end) were averaged for each tree, and the segment volume was computed as a cone (fig. 3). Also, direct volume

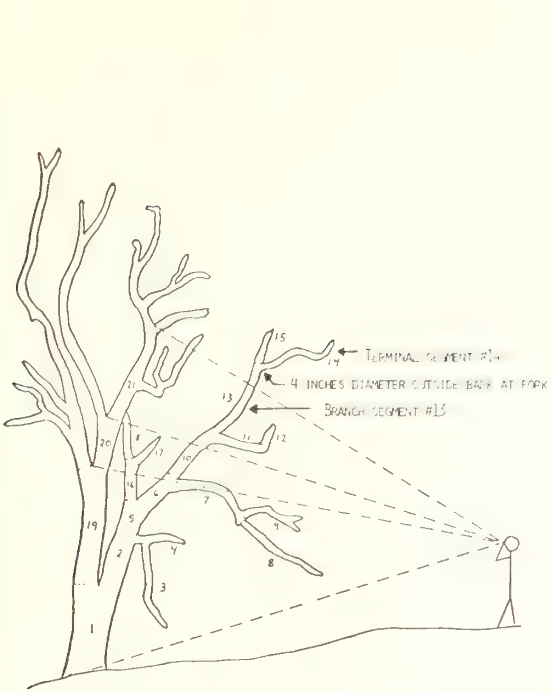

Figure 3--Volume determination of standing trees as determined by measuring segment diameters and lengths with a relascope. Segment volumes (numbered on sketch) are summed to obtain tree volume.

data was obtained by a tree caliper and cloth tape after each tree was cut. Cut segment volume was computed in the same manner as for standing trees (Pillsbury and Stephens 1978).

For both standing and cut trees, the sum of all segment volumes provides both an indirect and direct measurement of the total tree volume. Cut and standing measurements were obtained for a sample of 61 trees of different species located throughout the study area. The relationship between standing and cut tree volumes is shown in figure 4. This equation was used to adjust indirect volume measurements for the remaining 109 trees in the study.

Twenty-six sample plots (fig. 1) were randomly selected in hardwood stands at sites which appeared to be similar in size distribution and volume to the surrounding stand. A total of 170 trees, totalling 7,880 cubic feet (223 cubic meters) of wood, were measured by the technique shown in figure 3. Tree volume equations listed in table 1 were developed by multiple regression. Two independent variables, diameter at breast height and total tree height, provided the best correlation to tree volume. The addition of tree form, soil and site variables did not improve the correlation at the 5 percent level of significance and were eliminated from further consideration in the analysis.

Hardwood Weight Tables

Tree weights were obtained from 84 trees. Each tree was cut into firewood-size pieces 18 inches (45 cm) long and loaded on to a flatbed truck where each tree was weighed by a set of portable truck scales on loan from the California Highway Patrol. Merchantable tree weight is green weight, excluding foliage and branches less than 2 inches (5 cm) in diameter. A total of 250,000 pounds (113,000 kg) of wood was cut and weighed.

A strong correlation was found between volume and weight values (multiple correlation coefficient, R^2 = 0.904 or higher for individual species), and this relationship was used to estimate weight values for uncut trees. Tree weight equations shown in table 1 were developed using diameter at breast height and total tree height as independent variables.

Volume and weight tables for coast live oak, blue oak, tanoak, valley oak, and a general all-species table resulted (Pillsbury and Stephens 1978).

Stand Characteristics for Central Coast Hardwood Species

While individual tree measurements were required for volume and weight table development, total data from each plot were used to gather information about the stand itself. The computed stand characteristics are shown in Appendix A, Stand Variables. Data are expressed on a per acre basis, *e.g.*, individual tree volumes are summed to obtain plot volumes, and

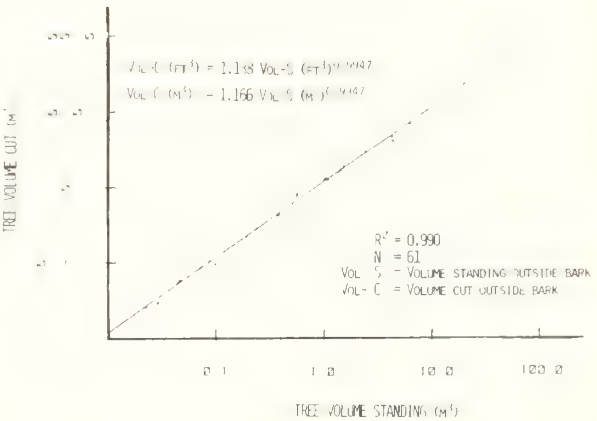

Figure 4--Relationship between tree volume standing and tree volume cut for 61 trees in the Central Coast counties, California.

Table 1. Tree volume and weight equations for Central Coast hardwoods.

Species	Equation	R^2	n
All species	$VOL\ (ob) = 0.00469458\ (DBH^{2.2633})(HT^{0.7126})$	0.944	170
	$VOL\ (ib) = 0.00371214\ (DBH^{2.1731})(HT^{0.7631})$	0.945	170
Coast Live Oak	$VOL\ (ob) = 0.01632627\ (DBH^{1.6725})(HT^{0.8259})$	0.916	56
	$VOL\ (ib) = 0.01045289\ (DBH^{1.6855})(HT^{0.8236})$	0.902	56
Blue Oak	$VOL\ (ob) = 0.00105029\ (DBH^{2.3660})(HT^{1.0966})$	0.943	55
	$VOL\ (ib) = 0.00072834\ (DBH^{2.3990})(HT^{1.1057})$	0.942	55
Tanoak	$VOL\ (ob) = 0.00347878\ (DBH^{2.0397})(HT^{0.8802})$	0.989	20
	$VOL\ (ib) = 0.00475941\ (DBH^{1.9333})(HT^{0.8190})$	0.989	20
Valley Oak	$VOL\ (ob) = 0.00077572\ (DBH^{2.3348})(HT^{1.1298})$	0.989	20
All species	$MWT = 0.81259\ (DBH^{1.9434})(HT^{0.6899})$	0.931	150
Coast Live Oak	$MWT = 0.6464167\ (DBH^{1.8148})(HT^{0.8496})$	0.905	56
Blue Oak	$MWT = 1.2193549\ (DBH^{2.1964})(HT^{0.4191})$	0.901	55
Tanoak	$MWT = 0.1199063\ (DBH^{2.0287})(HT^{0.9821})$	0.982	20

Key:

VOL (ob) is total tree volume outside bark in cubic feet
VOL (ib) is total tree volume inside bark in cubic feet
MWT is merchantable green weight in pounds to a 2" stem
DBH is diameter at breast height in inches
HT is total height in feet
R^2 is multiple correlation coefficient
n is the number of observations

Table 2. Stand and yield characteristics for Central Coast hardwoods.

Variable Name	Units	Average	Range	Standard Deviation
Volume outside bark per acre	ft^3/ac	3012.34	630.0 - 9800.0	2454.60
Number of cords[1] per acre	#/ac	37.70	7.9 - 122.5	30.70
Volume inside bark per acre	ft^3/ac	2287.87	519.0 - 7681.0	1960.21
Green weight per acre	tons/ac	96.03	16.92- 260.02	69.12
Number of trees per acre	#/ac	235.21	1.0 - 1718.0	358.38
Basal area per acre	ft^2/ac	113.93	17.0 - 261.0	74.45

[1] Amount of wood stacked in a 4' x 4' x 8' space. Computation is based on a volume outside bark of 80 cubic feet (62.5%) of actual wood per cord.

extrapolated to obtain volumes per acre. Other stand variables are calculated in a similar manner. Results for species in the Central Coast counties are shown in table 2. Total stand volume (outside bark) and weight averaged 3010 cubic feet per acre (211 cubic meters per hectare) and 96 tons per acre (215 metric tons per hectare). Assuming that a standard cord (wood stacked in a 4' x 4' x 8' space) contains an actual volume of 80 cubic feet of wood, the average hardwood stand in the Central Coast counties contains about 37.5 cords per acre, and a cord weighs about 5100 pounds. A large variation exists for these and other variables measured because of the wide range of densities included in the sample design.

Stand Density Classes

Because hardwood stands were found to occur in a wide range of volume weight, number of trees/acre, and basal area densities, it is desirable to categorize hardwood stands by specific density classes. A correlation matrix was calculated to evaluate the degree of correlation among stand density variables. Variables with the highest correlation, measured by the correlation coefficient (R^2), that are easily measured or estimated were used to establish density class limits. The frequency of plots sampled and the range of stand volume and weight values were divided into stand density classes (I, II, III in table 3). The limits and averages used to define each class are shown in table 3.

Stand density classes may be used on maps to show relative distributions of hardwood volume and weight. A stand density class can be obtained by determining the volume per acre from a sample plot and referring to table 3. An easier method has been found based on the high correlation between basal area per acre and weight per acre ($R^2 = 0.90$). This method uses the variable plot sampling technique described by Dilworth and Bell (1971). The basal area is obtained by counting the number of trees observed from the center of each sample plot multiplied by the basal area factor stamped on an angle gage, wedge prism or relascope. This value is the basal area per acre. The density class and average volume and weight per acre can be obtained from table 3.

Summary

Based on this research, land and resource managers now are able to quantify hardwood

Table 3. Stand density class limits and averages[1]

Density Class	Volume (ob) in cubic feet/acre		Green weight in tons/acre		Basal area in square feet/acre	
	Average	Range	Average	Range	Average	Range
I	974	1 - 1430	32	1 - 55	37.3	1 - 70
II	2335	1431 - 4300	80	56 - 135	105.9	71 - 155
III	6862	4310+	206	136+	220.7	156+

[1] Averages are based on the average value measured per density class from plot data.

species and stands by:

1. Determining individual tree volume and weight.
2. Obtaining a general estimate of stand volume and weight per acre.
3. Compiling a detailed estimate of stand volume and weight per acre.

Specific examples and recommended techniques are discussed in Hardwood Stand Density Characteristics for Central Coast Counties in California (Pillsbury 1978).

CURRENT HARDWOOD STUDIES AND ANTICIPATED RESULTS

Aerial Photo Volume and Weight Tables

Other studies in progress include the development of hardwood photo volume and weight tables. Low altitude (scale of 1:5,000) color photographs have been taken and processed by the U.S. Forest Service.[5] Tree height, crown diameter, and crown area measurements are being determined for 168 sample trees located on 21 plots in the Central Coast counties (fig. 1). Values are being obtained from two types of photo measuring equipment. The first type is a digitized Wild STK-1 stereocomparator and card-punch combination. This equipment provides high precision measurements; however, it is very expensive to purchase or lease. Secondly, the relatively common, less expensive parallax bar is used although it has lower precision. A comparison of measurements taken by these two types of equipment will allow us to determine the degree of variability that can be expected from low precision equipment. The relationship between tree measurements obtained from aerial photos and from volume and weight calculated from field measurements will be used to develop photo volume and weight tables as outlined by Paine (1978).

These tables will be used to determine volume and weight of individual trees from aerial photos. Volume and weights for small stands of hardwoods can be estimated by taking measurements from a series of photo sample plots. Photo volume and weight tables will be used for classifying homogeneous hardwood stands into volume and weight density classes for the fuel inventory mapping project.

Hardwood Fuel Inventory Maps

Determining hardwood volume and weight distributions for the Central Coast counties is the primary objective of this study. This will be accomplished by generating a set of hardwood fuel inventory maps. The U.S. Geological Survey, Land Use and Data Analysis (LUDA) Program has prepared vegetation cover maps (scale of 1:24,000) for the Central Coast counties. These maps will be used as "base maps" for the fuel inventory project. Forest lands are divided into deciduous, evergreen, and mixed forest land (Anderson *et al* 1976). Volume and weight estimates from aerial photos will be used to obtain stand density classes (table 3) for the deciduous forest lands. Deciduous forest lands will be subdivided into stand density classes I, II or III and mapped on USGS topographic maps. Photo estimates will be checked in the field to assure correctness of classification.

Fuel inventory maps will provide regional estimates and distribution of hardwoods. Also, woodland owners, with assistance from resource agency personnel, will be able to identify their property on these maps and obtain volume and weight estimates for the hardwood portions.

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[5] U.S. Forest Service, State and Private Forestry, Region 5, San Francisco, California.

Thus, a hardwood volume and weight estimate will be obtained for the Central Coast counties for the first time.

OUTLINE OF FUTURE STUDIES FOR CENTRAL COAST HARDWOODS

Future studies planned for the Central Coast hardwoods include growth and yield evaluation and analysis of regeneration, thinning, and stand improvement techniques. This information is essential before management recommendations can be made. Further studies will analyze the percentage of harvest that will allow for proper soil and watershed protection.

Most woodland owners do not have retail outlets nearby and do not have the time to transport firewood to high demand metropolitan areas where prices are favorable. Studies are needed to evaluate how a local economy might benefit from an oak-woodland cooperative.

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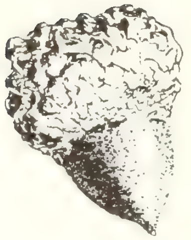
APPENDIX A. Summary of tree and stand variables for Central Coast Counties in California.

Variable	Units	Measurement description
A. Tree Variables		
Species	code	1. coast live oak; 2. blue oak; 3. valley oak; 4. madrone; 5. tanoak; 6. interior live oak.
Diameter at breast height outside bark	in	Diameter of main stem at 4.5' (1.35 m) measured with a D-tape.
Total tree height	ft	Determined by relaskop.
Crown area	ft^2	Computed from average of maximum and minimum crown diameter (based on circle).
Volume outside bark (standing)	ft^3	Computed from segment end diameters and segment lengths by relaskop (fig. 3).
Volume outside bark (cut)	ft^3	Computed by tree calipers and cloth tape or figure 4.
Volume inside bark (cut)	ft^3	Volume outside bark (cut) minus volume lost due to bark.
Merchantable tree weight (green)	lbs	Green weight excluding foliage and growths less than 2 in (5 cm) in diameter, by truck scales.
B. Stand Variables		
Volume outside bark	ft^3/ac	Technique described by Dilworth and Bell (1971); data obtained from tree variable measurements (part A).
Volume inside bark	ft^3/ac	
Merchantable tree weight (green)	tons/ac	
Basal area	ft^2/ac	
Number of trees	#/ac	



Quercus kelloggii

Oaks in California's Commercial Forests—Volume, Stand Structure, and Defect Characteristics[1]

Charles L. Bolsinger[2]

Abstract: Information on area of hardwood types on commercial forest land in California, and volume and defects of oaks is summarized. Studies done in Trinity County and the southern Sierra Nevada show similar species, size, and defect characteristics. Black oak made up 60 percent of the volume. Most stands had less than 1,000 cubic feet per acre. Larger older trees were more defective than smaller, younger trees. About one-fourth of the trees under 11.0 inches in diameter had visible decay indicators, compared with 100 percent of the trees over 29 inches. About half of the black oaks over 29 inches in diameter were cull.

INTRODUCTION

California has 16.3 million acres of forest land, excluding Parks and Wilderness Areas, capable of growing 20 or more cubic feet of industrial wood per acre annually. All but about 50,000 acres of this "commercial forest land" is capable of growing conifers, though currently hardwood forest types cover 2.8 million acres. About 77 percent is on private lands, 15 percent is in National Forests, and 8 percent is on other public lands. By site class, the hardwood types are distributed as follows:[3]

Site class (cubic feet per acre per year)	Thousand acres	Percent
20-49	267	9
50-84	968	34
85+	1,606	57
Total	2,841	100

In addition to the hardwood types, hardwood trees make up 10 percent or more of the stocking on 2.7 million acres of commercial conifer types.

About 80 percent of the total cubic-foot volume in hardwoods in California is oaks[4] (including *Quercus spp* and *Lithocarpus densiflorus*) as shown below (see also species list at end of this article).

Species or species group	Million cubic feet in trees 5.0 inches+	Million board feet (Int. 1/4" rule) in trees 11.0 inches+
California black oak	1,078	2,659
White and live oaks	718	1,771
Tanoak	1,087	2,048
Madrone	544	1,024
Red alder	64	179
All other hardwoods	202	394
Total	3,693	8,075

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[1] Presented at the Symposium on Ecology, Management, and Utilization of California Oaks. Claremont, California, June 26-28, 1979.

[2] Research Forester, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

[3] See Griffin and Critchfield 1972 for details on the distribution of hardwoods in California.

[4] Not included is the volume of oaks on over 7 million acres of unproductive oak woodland, consisting primarily of California blue and valley oaks and California live, interior live, and canyon live oaks. No volume inventory has been made of these species except where they occur on "commercial forest land."

These estimates of forest area and timber volume were made by the Renewable Resources Evaluation Research Unit at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Volume was calculated for trees having at least one 8-foot log above a 1-foot stump to a top diameter of 4 inches outside bark for cubic-foot estimates, and 9 inches for board-foot estimates.

To approximate the total volume in hardwoods on California's commercial forest land, factors were developed as follows: A sample of trees measured by the Resources Evaluation Unit were selected and main bole net volumes were calculated. Values developed by Pillsbury and Stephens (1978) in California's central coast area were used to estimate total tree volume including stumps, limbs, branches, and tops in the same trees. Conversion factors were calculated by broad diameter class and applied to the State totals. Because the species mix in Pillsbury's study differs from the total mix of hardwoods in California, these results can be viewed only as rough approximations:

Diameter at breast height	Net cubic-foot volume of main bole from a 1-foot stump to 4-inch top (A)	Conversion factor--total tree volume/main bole volume (B)	Approximate total tree volume (A) x (B)
Inches	Million cubic feet		Million cubic feet
5.0-10.9	1,047	1.56	1,633
11.0-14.9	725	1.90	1,378
15.0-20.9	857	1.98	1,697
21.0-28.9	691	1.98	1,368
29.0+	373	1.98	738
Total	3,693	1.84	6,814

A similar relationship between main bole volume and total tree volume was reported by Noel Cost (1978) in mountain hardwoods in North Carolina. Cost's study consisted mostly of smaller trees. His factor--1.46--is similar to the 1.56 shown above for trees in the 5.0- to 10.9-inch class.

Although oaks occur naturally on 5.5 million acres of commercial forest land, logging practices have promoted their growth and establishment.

Since 1953 (USDA Forest Service 1954), cubic-foot volume of oaks has increased 34 percent while conifer volume has decreased 29 percent. Selective cutting has removed conifers from mixed stands, often leaving oaks to control the site. McDonald (1973) reported that oak stocking on the Challenge Experimental Forest increased following logging to meet the former California Forest Practice Act Standards. Although current standards allow oaks to count as stocking only if designated for management (California, State of, 1975) their presence influences stand development even when not counted. Logging promotes oak in many areas of California.

A canvass of 100 percent of California's forest products industries in 1976 showed that hardwoods amounted to less than one-fourth of 1 percent of wood consumed (Hiserote and Howard 1978). Conifer consumption was 135 percent of annual growth and 2.1 percent of inventory, while industrial hardwood consumption was 6 percent of growth and 0.1 percent of inventory. Some hardwoods were used as fuel. About 1.5 million cubic feet of fuelwood was harvested by timber operators (California Department of Forestry 1977), and 47,707 fuelwood cutting permits were issued by the USDA Forest Service. An unknown but substantial portion was oak. Still, the total consumption of oak in Californi is a small fraction of the resource.

The effect of removing conifers from mixed stands and leaving hardwoods is seen in a stand sampled in Trinity County. This stand was logge about 20 years ago and again within the past 10 years. The older logging removed large pines. Recent logging removed large Douglas-fir No hardwood trees were cut or killed by logging, but many hardwoods--mostly California black oak and canyon live oak--were damaged. Trees and stumps were tallied so stand data could be displayed before and after the recent logging. The results are:

Stand component	Square feet of basal area per acre in trees 5.0 inches+				Saplings & Seedlings per acre at time of sampling	
	Before logging		After logging			
	Total BA	Percent	Total BA	Percent	Number	Percent
Conifers	56	52	24	32	342	26
Hardwoods	52	48	52	68	960	74
Total	108	100	76	100	1,302	100

In this stand the proportion of hardwood stocking increased 20 percent after removal of dominant Douglas-fir trees. A closer examinatio revealed that many of the hardwoods were crooked and/or rotten. Of more importance is the long-term effect. The future forest, represente by the saplings and seedlings, is three-fourths California black oak and canyon live oak.

To get a better idea of oak characteristics on commercial conifer site lands, two areas (see fig. 1) were selected for study: Trinity County in the Klamath Mountains and northern Coast Ranges, and a five-county area in the southern Sierra Nevada and the Tehachapi Mountains (Mariposa, Madera, Fresno, Tulare, and Kern Counties). Forest Survey plot records for lands outside National Forests were examined.[5]

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[5] Field plots were randomly selected from a larger sample of aerial photo plots and established on the ground. For details on the sampling procedures see Bolsinger 1976 and 1978.

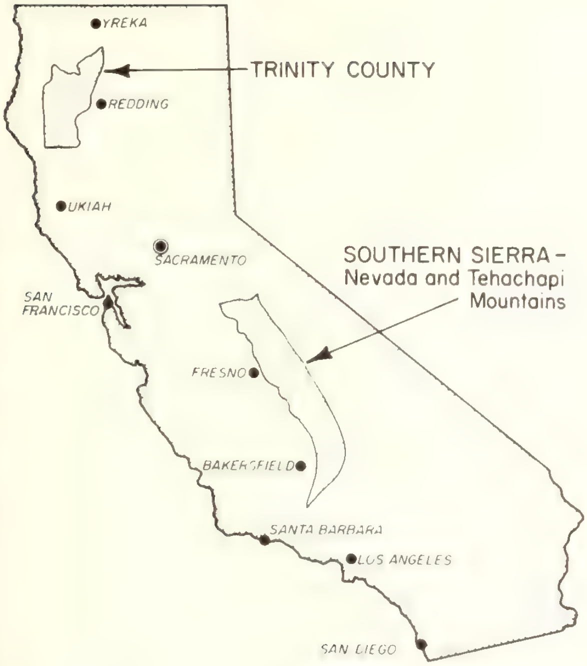

Figure 1--Map of California showing location of oak study areas.

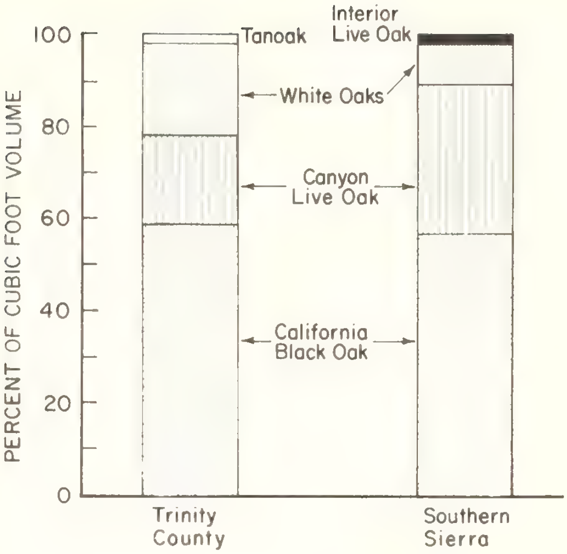

Figure 2--Percent of total net volume of oaks by species, Trinity County and southern Sierra Nevada.

The following summary shows area and number of plots:

Study area	Acres of commercial forest land	Number of field plots	Percent of plots with oak trees 5.0 inches+
Trinity County	460,000	118	70
Southern Sierra	174,000	65	60

Plots consisted of 10 points scattered over an acre. At each point trees were tallied and measured. Deductions were made for visible indicators of decay, missing and broken parts, and crook. Net volumes were calculated and summarized by plot and area:

Study area	Average conifer volume in all plots	Average hardwood volume in plots with hardwoods	Hardwood plots by cubic-foot-per-acre volume class		
			1-449	500-99	1,000+
	- - - Cubic feet per acre - - -		- - - Percent - - -		
Trinity	2,696	376	70	20	10
Southern Sierra	2,442	497	62	33	5

In both study areas, nearly 60 percent of the total oak volume was California black oak (fig. 2). Canyon live oak and white oak made up most of the balance. In Trinity County the white oak was *Quercus garryana*, including the large tree form and the smaller var. *breweri*. In the southern Sierra Nevada, field crews identified both *Quercus garryana* and *Quercus lobata*. Tanoak accounted for about 2 percent of the oak volume in Trinity County. In the southern Sierra Nevada, interior live oak accounted for 2 percent of the oak volume.

Figure 3 shows that the distribution of oaks by diameter class was somewhat similar in both areas, though the southern Sierra Nevada has a higher proportion of larger trees than Trinity County.

Oaks in California often are crooked, forked, and sprawling, making them difficult to handle in conventional industrial processes. Oaks in California's conifer stands often are rotten and broken, especially large old trees. A number of wood-rotting fungi attack oak trees, including *Armillaria mellea*, *Polyporus dryophilus*, *P. sulphureus*, and *Fomes applanatus*, and several wound rot species of *Polyporus* (Hepting 1971 and McDonald 1969). Deductions in volume were made only for visible indicators. Figure 4 shows the proportion of the 1,183 oak trees tallied in the two study areas by soundness categories. Defect was much greater than the 3 percent found by Pillsbury and Stephens (1978) in oaks in California's central coast. Their study included total wood volume, not just bole volume, and contained no California black oak.

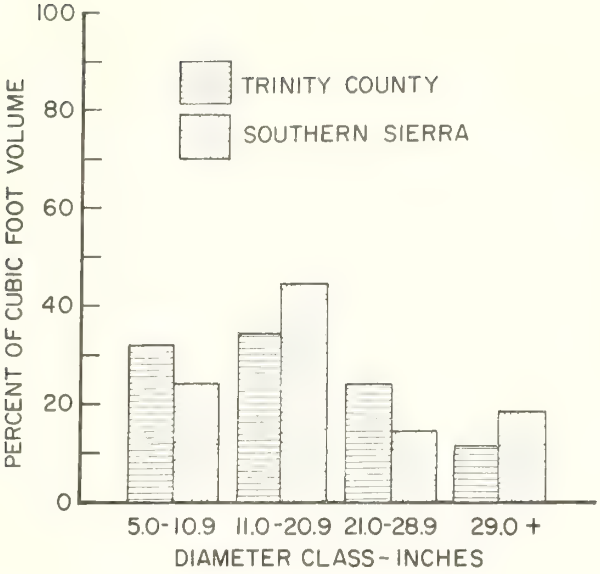

Figure 3--Percent of total net volume of oaks by diameter class, Trinity County, and southern Sierra Nevada.

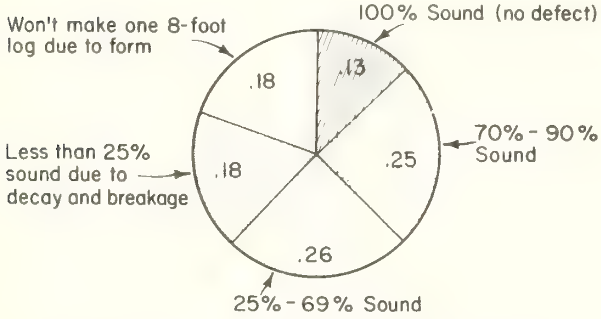

Figure 4--Proportion of oak trees tallied in Trinity County and southern Sierra Nevada by soundness categories (basis: 1,183 trees).

In both Trinity County and the southern Sierra Nevada, California black oak was found to have a higher incidence of decay than other oak species. Figure 5, for example, shows that 23 percent of the black oak trees in the southern Sierra were cull[6] due to decay compared with 9 percent of the canyon live oak and 13 percent of the interior live oak. Because much of the decay was confined to butt sections of trees, inclusion of top and limb wood volume as done by Pillsbury and Stephens would decrease the average proportion of defect.

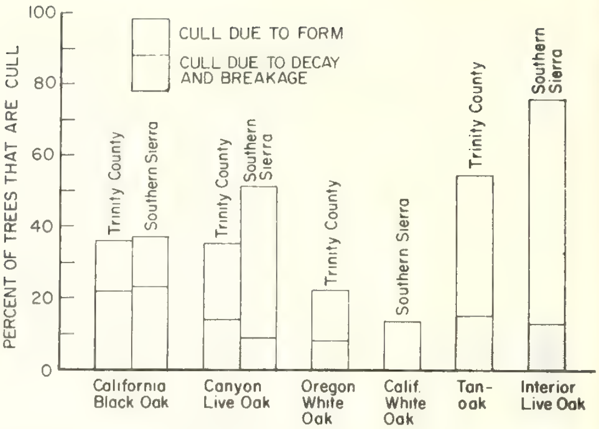

Figure 5--Percent of oak trees on commercial forest land in Trinity County and southern Sierra Nevada that were cull due to form and cull and breakage.

Larger, older trees are more defective than the younger, smaller trees. About 6 percent of the black oak trees in the 5.0- to 10.9-inch diameter class were cull because of decay, compared with 22 percent of 11.0- to 20.9-inch trees and 50 percent of trees 29.0 inches and larger (fig. 6). Similar patterns held for

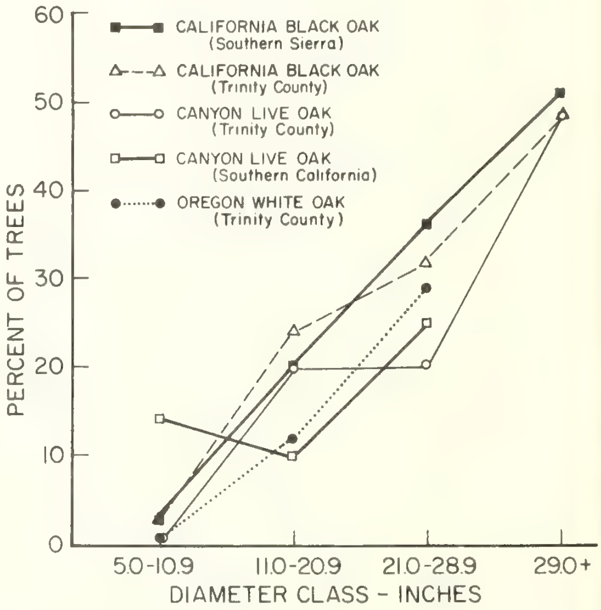

Figure 6--Percent of trees tallied in Trinity County and the southern Sierra Nevada that are cull due to decay and breakage.

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[6] Cull trees are less than 25 percent sound, or won't make one 8-foot log.

other oaks. Much of the defect seemed related to logging wounds and fire scars. Because deductions were made only for visible indicators of defect, these cull estimates are considered to be conservative. Decay indicators were: visible rot, hollows, breaks, and fungus sporophores. The following tabulation shows percent of trees by diameter class with visible decay indicators:

Diameter class	Percent of trees with indicators
inches	
5.0 - 10.9	28
11.0 - 20.9	65
21.0 - 28.9	80
29.0+	100

Discussion

Oaks in California's commercial forests are currently an underutilized resource, and they have been increasing. The oaks are valuable as wildlife habitat and important in watershed protection. Their presence adds to the unique character of California's forests. They are an essentially untapped resource for energy and other uses. Development of a use for these species would have many positive results, including an economical way to release conifers from competition on extensive areas. Any technology that is developed has to take into account the defective nature of these trees. For example, oaks suitable for lumber products usually must be fairly large, yet most large oak trees contain substantial amounts of cull. Smaller oak trees could be suitable for firewood and other uses for which the presence of decay or other defect would not be critical. In some areas, oaks may promote the establishment and early survival and growth of conifers by creating a more favorable soil pH and sheltering them from the harsh summer sun. It may be possible to grow both oaks and conifers on the same piece of ground. Oaks would be the nurse crop; they could be harvested when the conifers are large enough to make it on their own in the sun. Under intensive management, undesirable features of oak such as decay and crook could be minimized.

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SCIENTIFIC AND COMMON NAMES OF TREES

Scientific name	Common name
Alnus rubra Bong.	red alder
Arbutus menziesii Pursh	madrone
Lithocarpus densiflorus (Hook. & Arn.) Rehd.	tanoak
Quercus agrifolia Nee	California live oak, coast live oak
Q. chrysolepis Liebm.	canyon live oak
Q. douglasii Hook. & Arn.	blue oak
Q. garryana Dougl.	Oregon white oak
Q. garryana var. *breweri* (Engelm.) Jeps[7]	Brewer oak
Q. garryana var. *semota* Jeps[7]	Kaweah oak, shin oak
Q. kelloggii Newb.	California black oak
Q. lobata Nee	California white oak, valley oak
Q. wislizenii A. DC.	Interior live oak
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir

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[7] From Griffin and Critchfield (1972).

Silviculture and Management

Preliminary Recommendations for Managing California Black Oak in the Sierra Nevada[1]

John Tappeiner and Philip McDonald[2]

Abstract: Ecologically, California black oak is an important species in mixed-conifer and ponderosa pine forests. The occurrence of this oak in these forests is reviewed in terms of site considerations, species composition and stand structure. Its response to fire and role as a nurse crop for conifers are discussed. This discussion, along with a brief summary of current research findings, leads to recommendations for managing this oak for wildlife, wood and aesthetics in the Sierra Nevada. We envision growing pure black oak in groups which range from about 0.5 to 10 acres. On poorer sites this oak appears to be able to maintain itself, while on better sites treatment will be necessary to counteract the natural succession toward conifers.

INTRODUCTION

Recent interest in more intensive management of California black oak (*Quercus kelloggii* Newb.) in the Sierra Nevada, especially for wildlife habitat, has stimulated development of preliminary management recommendations for this species. These are based on McDonald's (1969, 1978) work, discussion with silviculturists throughout California, and field observations of both authors. It is our hope that presenting these recommendations will lead to their discussion and improvement. They should be considered only as preliminary.

Any silvicultural prescription depends upon the objectives and the products for which a stand is managed. Stand management objectives depend, in part, upon site productivity, species composition, stand structure, and economic alternatives. In addition, prescriptions must be developed on a stand-by-stand basis with careful regard to the ecological forces interacting on the stand. The recommendations that follow are intended to match the ecology of this oak to management considerations.

California black oak is found in essentially three broad vegetative categories, and we feel that stand management will differ somewhat in each. Furthermore, these guidelines are aimed not only at stands managed for wood products, but also at those where wildlife and aesthetics are emphasized.

Before we present these recommendations, background must be given to show their basis and logic. This background will consist of a brief presentation on site productivity, species composition, and structure of California black oak stands, as well as this oak's role as a nurse crop for conifers, its response to fire, and its reproduction from seed and sprouts.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Regional Silviculturist, Pacific Southwest Region, Forest Service, U.S. Department of Agriculture, San Francisco, California 94111; and Research Forester, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Redding, Calif. 96001

California black oak is found in three broad vegetation types: (1) conifer forest (Pacific ponderosa pine, Pacific ponderosa pine--Douglas-fir, and Sierra Nevada mixed conifer), (2) California black oak, and (3) oak woodland-chaparral.

Recommendations for management of black oak in the conifer forest are presented in detail. We will only briefly mention management possibilities for this oak in the other types.

BACKGROUND

Site Productivity

California black oak is found on a wide range of sites. It grows vigorously on deep well-drained soils of loam or clay-loam texture and does well on sandy, gravelly, or stoney soils. Poorly drained soils, however, restrict downward root penetration and lead to its early demise. This oak is often found occupying the poorer, harsher sites. However, its best development is on high sites--sites where the conifers are more competitive and hence responsible for eventually reducing oak density.

Stand Structure

Vegetative associates are several species of conifers, other hardwoods, and woody shrubs. Most conifers inherently grow taller than this oak, and given enough time, will overtop it. Because the oak cannot tolerate shade when mature, it loses vigor and usually dies once overtopped. California black oak is favored by disturbance such as fire, which often kills competitive vegetation, but only kills the oak back to ground line. It quickly sprouts, and if present in sufficient numbers, forms a closed canopy. Thus, the purest stands of oak often are found on poorer sites and in areas of heavy past disturbance.

In natural young-growth ponderosa pine and mixed-conifer stands, black oak is found as scattered individual trees and in small groups. Scattered trees are most common on better sites, while groups generally occur on moderate sites on south slopes or in small draws and areas of rocky soil. Within the groups there usually is not a wide range of age classes. In fact, because of sprout origin, most trees in a group are of one age. New saplings or poles established between disturbances generally are lacking.

On harsher sites, black oak stands tend toward being pure, especially in the northern part of the species' range. Where disturbance has been frequent, the black oak forest can be extensive, made up of a mosaic of even-aged stands, or sometimes of two-aged stands with large scattered old-growth trees above and more numerous young-growth trees below.

Black Oak as a Nurse Crop

On drier sites on south and west slopes with good soils, and at lower elevations, California black oak can be a nurse crop for conifer reproduction (Baker 1942, Tappeiner 1966). Often there appears to be a positive relationship between oak shade and the occurrence of conifer seedlings, saplings, and poles on slopes otherwise occupied by bear-clover (*Chamaebatia foliolosa*) or other woody shrubs. Apparently the conifers are not affected as much by the oaks as they are by the less shade-tolerant shrubs. Generally, regeneration under oaks is a slow process, and 20 years or more are often necessary for the area to become stocked with conifer seedlings. Even then, the presence of oak does not ensure adequate conifer regeneration.

While oak shade favors natural regeneration of conifers, it retards their later development. Ponderosa pine (*Pinus ponderosa*) is relatively intolerant and the lower light levels under oak, along with competition from established oak roots, slows its growth. Seedlings often appear weak and spindly and are frequently damaged by the reproduction weevil (*Cylindrocopturus eatoni*). Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and sugar pine (*Pinus lambertiana*) grow much better in oak shade as seedlings and saplings. Their leaders and crowns, however, usually are damaged as they grow through the oak branches. Also, their tolerance decreases with age, and light levels under oak may be somewhat low for their best development.

Fire

California black oak is severely damaged by crown fires and unless mature, even by relatively cool ground fires (McDonald 1969). Fire can kill the stem outright or cause "feathering" along the stem from epicormic branching. These branches are a serious lumber degrade, and in general are short-lived on all but open-grown trees. Fire-damaged stems are especially susceptible to pathogens, which weaken the tree and result in windthrow and breakage. Therefore, fire must be used with caution, if at all, in managing saplings or older black oak trees. Mixed-oak and conifer stands in general may not be compatible with burning if good quality oak wood is an objective of stand management.

It is possible that fire could be used to stimulate suppressed advance oak reproduction and this possibility needs careful study on several sites. Often, older oak seedlings, which are 0.5 to 2.0 feet (0.1 to 0.6 m) tall and about 20 years old, grow under large oak trees in competition with tolerant conifer seedlings and saplings and various shrubs. These oak seedlings are often repeatedly browsed. Fire might reduce the vegetative competition and result in seedling-sprouts more vigorous and of better form than the seedlings. Fire would kill the advance oak reproduction back to ground line. The oak probably would sprout from the root crown, often with only one stem, and quickly grow beyond browse height.

Reproduction

At present, foresters have had little experience in outplanting black oak; therefore, they must rely for the most part on natural regeneration, which is composed of advance reproduction and stump sprouts. McDonald (1978) noted the following points with regard to regeneration:

Natural oak seedlings and advance reproduction

a. In young-growth stands, large seed crops occur every 5 to 6 years, and seem to either be excellent or nonexistent. Inclement weather and insect infestation often reduce seed crops greatly.

b. Height growth of new seedlings averages only about 0.1 foot (3 cm) per year, advance growth about 0.3 foot (9 cm) per year for the first 5 growing seasons.

c. High mortality of acorns and newly germinated seedlings is common.

d. Advance reproduction of black oak often is quite plentiful, averaging 500 to 800 seedlings per acre (1200 to 2000/ha) in mixed conifer and hardwood stands.

e. Tree form often is better if the tree is from seed, rather than from sprouts.

Reproduction by sprouting

a. After cutting, black oak sprouts vigorously from the root crown or the stump.

b. Stumps should not be higher than 8 inches (20 cm) in order to obtain sound, windfirm and reasonably straight sprouts.

c. Stool sprouts originate from tall stumps caused by cutting or breakage of the tree. They are weakly attached to the stump and are peeled off easily by wind and snow. They also are prone to heart rot introduced from the stump. For these reasons they are undesirable and to be avoided.

d. Sprouts from the root crown grow about 2 feet (0.6 m) per year in clearcuttings and about 0.7 feet (0.2 m) per year in shelterwood cuttings.

e. In clearcuttings and burns black oak stump sprouts will outgrow planted or natural conifer seedlings for at least 15-20 years. Thus, planting these areas with conifers does not eliminate oak from the new stand.

Artificial regeneration

Black oak can be established by artificial regeneration if a good seedbed free of competing shrubs and trees is provided. Newly fallen acorns should be gathered in the fall or spring, and outplanted when just beginning to germinate. Pinned-down cone screens must be used for protection from rodents, especially squirrels. With use of these techniques, on a high site in north central California, survival after 10 years was 40 to 45 percent. Annual fertilization with 0.25 pound (0.1 kg) per seedling of 16-20-0 enhanced survival and height growth. Fertilized seedlings were 2.5 feet (0.8 m) tall after 5 years and over three times taller than unfertilized seedlings. Protection from pocket gophers, and at specific locales in California protection from deer and cattle, would aid in seedling establishment.

Thus it appears that regeneration of California black oak is most likely to be successful with sprouts in clearcuttings. Seedling-sprouts, if plentiful, could enhance stocking if burned or slashed and stimulated to a higher growth rate by so doing. Artificial seeding has promise and this technique should improve with experience.

Stand Density - Thinning

To obtain the proper density and quality of black oak trees to increase stand productivity, thinning often will be necessary. Such treatment should promote good stem and crown development and even enhance the value of wildlife and aesthetics. Stump sprouts can be thinned, beginning about 4 years after sprouting, but earlier thinning generally results in additional sprouting (McDonald 1978). Thinning at an early age (4 to 8 years), has the advantage of smaller material to cut and less slash to dispose of, but this practice should be used with caution because there is an indication that early thinning may result in forked trees. And thinned sprouts grow no faster than unthinned sprouts, at least for the first 10 years after thinning.

To produce well-formed trees with no loss of stand increment, thinning of natural stands should be done when sprouts and seedlings are 30 to 50 feet (9 to 15 m) tall or when the stand exceeds 125 square feet of basal area per acre (29 m^2/ha). On a high site in north central California, 60-year-old hardwood stands thinned at 100 to 125 square feet of basal area per acre (23 to 29 m^2/ha) tentatively produced the most cubic volume for the first 8 years after thinning. On lower sites this residual level of growing stock could be too high and 80 to 100 square feet per acre (18 to 23 m^2/ha) might be more appropriate.

Where accessible, thinning can be done for fuelwood, usually at no cost to the owner. In thinning and other stand tending, trees of seed origin should be favored as they usually have good form.

In the future, plantations from seed will be established at different spacings, and from them will come thinning schedules that will maximize growth and value. Such schedules may differ from those for stands of sprout origin. It is likely that the thrifty, more fully-crowned plantation-grown trees so produced, will yield abundant acorns at a much earlier age than the narrow-crowned trees in the dense sprout stands of today.

RECOMMENDATIONS

Following are preliminary recommendations for management of California black oak in the three broad vegetative types defined earlier. They serve as a starting point; use them with caution.

Conifer Forest Type

1. Black oak on poor sites on west and south slopes should be maintained in pure stands. It should be relatively easy to do so. On better sites, the species is subject to overtopping by conifers and considerable stand manipulation will be needed to maintain a constant proportion of groups of well-developed oak trees.

2. For practical management of mixed black oak-conifer stands, black oak should be grown in pure groups with a range in size of about 0.5 to 10 acres (0.2 to 4 ha). In this manner, treatments favoring oak can be applied to discrete parts of the stand. Because the smaller groups generally are more common where the site is higher and the larger groups are located where the site is lower, management will follow accordingly. Large stands on poor sites probably should remain natural unless uses are well defined. Groups of oak are common in mixed-conifer stands, and it should be necessary only to recognize and recommend for them in silvicultural prescriptions; only occasionally will special treatment be necessary to establish new groups. Furthermore, managing oaks in groups will aid the orderly management (regeneration, release, logging, slash disposal) not only of the oak, but also of the surrounding conifers.

3. The number of various-sized oak groups recommended for retention or creation in each compartment cannot be answered here. It will depend on the use or mix of uses and their intensity, which in turn is geared to management goals.

4. If oak is to be used as a nurse crop for conifers, its canopy density must be regulated for best conifer development. Need for periodic opening-up of the stand depends primarily on the tolerance and size of the conifers and the density of the oak canopy.

5. If used in stands with oaks in them, fire should be very light and confined to the ground surface. It must not be hot enough to damage oak stems and hence allow formation of heart rot. Fire can possibly be used to stimulate height growth of oak advance reproduction.

6. Because of the slow growth rate of natural reproduction, oak regeneration should be accomplished mostly from root crown sprouts or from advance reproduction. Stumps should be lower than 8 inches to avoid stool sprouting.

7. Thinning of oak should begin when stems are 30 to 50 feet tall and obviously overcrowded. After thinning, basal areas of 100 to 125 square feet per acre should be satisfactory for cubic volume growth on good sites, with somewhat lower density on sites of lesser quality. The reduced stand density brought about by thinning should create a more open stand with a longer view and hence be more pleasing aesthetically.

8. Because the incidence of heart rot increases in stands over age 80, these stands are increasingly poor risks. Yet acorn production increases after age 80. Thus, a compromise between wood and acorns may often be necessary for multiple-use management. At least two broad age classes (0 to 80 and 81 to 120+ years) should be maintained for continuous mast production.

9. In areas where oaks already are aggregated, artificial regeneration of conifers after fire or clearcutting does not preclude oak management. Of course, the oak group and about 20 feet (6.1 m) of buffer need not be planted. The oaks will sprout and the sprouts will grow faster in height than the conifers and thus be competitive with them at least for several decades. Trees from these sprouts can be precommercially thinned along with the surrounding conifers and thus groups of oaks will again be present in the mature stand.

California Black Oak Type

This type consists of nearly pure black oak stands, some of which are quite extensive. Without fire the stands will remain pure on poor sites and probably slowly change to mixed oak-conifer stands on better sites. The large number of trees and hence concentrated volume of wood could lead to development of an intensive program of stand management and utilization. Because many of these stands are found at low elevations, they form part of the important winter range for wildlife species. Thus the forest manager is faced with a number of manipulative possibilities for managing the different uses.

The preliminary stocking and regeneration recommendations listed above will probably apply to this type. To begin stand management both for mast and wood production, initial prescriptions could call for the removal of poorly formed or damaged trees. Growth then would accrue on the better stems. The poor quality trees could be sold for fuelwood.

Oak Woodland-Chaparral Type

In this type California black oak is an occasional associate on deep, well-drained soils. Here it generally is the dominant vegetation. It is often favored for shade, aesthetics, mast, and fuelwood in both suburban and rural settings. California black oak will reproduce by sprouts in this type and the material on vegetative reproduction should apply. Beyond this, however, the foregoing recommendations become increasingly questionable. Simply not enough information is available to recommend them with any certainty.

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Quercus kelloggii

An Approach to Managing California Black Oak and Hardwoods on a Deer Winter Range in Central California[1]

Donald Potter and Barbara Johnston [2]

Abstract: On the Stanislaus deer winter range, a method for determining stocking levels of California Black Oak (Quercus kelloggii) was developed. Mast needs for the deer herd and mast production per tree were first determined. The required number of oak trees per acre and percent of land to be occupied by oaks was calculated. A stand structure describing the distribution of the oak component in space and time was developed to achieve a desired balance between timber and deer production.

INTRODUCTION

The effects of timber management activities on the winter range of the Stanislaus deer herd have long been a management concern. Past timber management activities stressed optimizing growth and yield of commercial conifers. The wildlife biologists' primary concern was the decrease in oaks with accompanying decreases in acorns available to wintering deer. Guidelines for California black oak (Quercus kelloggii) retention often were developed on a small project basis, without data to quantify the effects of such recommendations area-wide. Recent availability of acorn production data by tree size and age, and other silvicultural information on California black oak, has enabled biologists and foresters to estimate the oak basal area required to support acorn production to meet the needs of specific densities of deer. Using this data, oak management guidelines to meet these requirements can be developed.

Information was needed on the following topics to develop recommendations for an entire winter range:

1. Population objectives for the Stanislaus herd.

2. A quantitative estimate of mast requirements for wintering deer.

3. A determination of oak basal area and stand structure needed over time to support the mast requirements.

4. A vegetative analysis of the winter range in order to identify how much and what kind of land was needed to meet basal area requirements. For example, the oak requirement could be met from combinations of marginal timber producing lands, isolated oak stands, stands in draws or on poor soils, as well as from intensively managed timber lands where oak was one of the managed species. This analysis was also necessary to measure present oak stocking levels in relationship to our objectives.

5. An evaluation of the effect of meeting various oak retention levels on timber production.

These interim oak management guidelines were developed through field discussion with foresters, silviculturists, and Forest Service and California Department of Fish and Game biologists. Although there are many other habitat elements which should be, and are being considered in managing the Stanislaus herd, we are addressing only the oak component on the winter range in this presentation.

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[1] Presented at the Symposium on Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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STUDY AREA

The winter range of the Stanislaus deer herd (Odocoileus hemionus californicus) occupies about 143,000 acres (57,870 ha) in an area bounded generally on the south by Highway 108 between Sonora and Long Barn, on the north by Highway 4 between Vallecito and Arnold, on the west by the Parrott's Ferry road between Vallecito and Sonora, and on the east by a line from Crandall Peak to Arnold. Approximately 45 percent of the area is National Forest land. Elevations range from 800 feet (243 m) to nearly 5500 feet (1,676 m). Mean elevation is about 3200 feet (975 m). Vegetation types include chaparral, oakwoodland, California black oak, ponderosa pine, and mixed conifer. Ponderosa pine (Pinus ponderosa) is the most abundant conifer species. Associated species include canyon live oak (Quercus chrysolepis), buck brush (Ceanothus cuneatus), deerbrush (Ceanothus integerrimus), mariposa manzanita (Arctostaphylos mariposa), and toyon (Heteromeles arbutifolia). Winter precipitation falls both as rain and snow. A deep winter snow pack generally does not develop, and southerly slopes usually are open most of the winter.

The area in which the guidelines were developed covers roughly 10 percent of the total winter range and is known as the Schaeffer compartment. Different guidelines were developed for southerly slopes. These slopes cover the quadrants from east through south to west and receive the greatest amount of winter sun. Deer use is much more intensive on these slopes and oaks are more abundant. North slopes cover those quadrants between west through north to east. North slopes receive much less deer use and have a higher conifer to oak ratio.

POPULATION OBJECTIVES

Population objectives have not been established for the Stanislaus herd, because the California Department of Fish and Game has not yet completed its management plan. However, Fish and Game and U.S. Forest Service biologists have developed an interim management objective on the winter range of 90 deer days use per acre per year on southerly facing slopes. Deer use has been measured as high as 90 deer days per acre by permanent transects in some areas in the Schaeffer compartment.

MAST REQUIREMENTS FOR DEER AND OTHER CONSUMERS

Acorns in the total diet of wintering deer have been found to range from 11 percent to 76 percent (Browning et al. 1973, Harlow et al. 1975). It is reasonable to assume acorns will constitute an average of 50 percent of the October-through-December diet of deer in the Sierra Nevada mountain range during good mast years (Barrett and Menke 3/, Goodrum and others 1971, Ashcraft 4/). Deer consume about 5 pounds (2.3 kg) of food per day, of which 2.5 pounds (1.1 kg) are acorns.

Although deer management is of prime concern, mast requirements for other acorn users like valley and mountain quail (Lophortyx californica and Oreortyx picta) and gray squirrels (Sciurus griseus) also are considered. The population objectives were set at 1 squirrel per 2 acres (0.8 ha) and 1 quail per 5 acres (2.0 ha) (Goodrum et al. 1971). The daily intake of a gray squirrel is about 0.22 pounds (100 gms) of food (Hawkins 1937, Uhlig 1956); of a quail, 0.02 pounds (9 gms) of food (Michael and others 1955). Asserson (1974) found acorns in the stomachs of gray squirrels in California to range from a low of 9.6 percent by volume in July to a high of 71.3 percent in December with an average of 50.9 percent over an eleven-month period. We are assuming acorns constitute about 50 percent of the diet of gray squirrels over a twelve-month period because of their acorn storage behavior,and about half the diet of quail over a three-month time span (Table 1).

Because only 50 percent of the acorn crop is likely to be sound and available to ground consumers because of encapsulation, abortion, and insect damage (Todd 1976, Barrett and Menke 3/),the 245 pounds (275 kg/ha) is arbitrarily doubled to a requirement of 490 pounds per acre per year (549 kg/ha).

Black oak acorn production is cyclic at 2- to 3-year intervals (Roy 1962). In intervening years acorn production often is low. In such

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3/ Unpublished report (A review of the value of hardwoods to wildlife in California with recommendations for research). R. H. Barrett and J.W. Menke, respectively, College of Natural Resources, Berkeley, and Department of Agronomy and Range Science, Davis, University of California,1976.

4/ Personal communication G.C. Ashcraft, California Department of Fish and Game, staff, December,1978.

	deer	squirrel	quail	total
a pounds of acorns/day freshweight	2 5	0.1	0.01	
b. population objectives acres/animal	1[1]	2	5	
c. pounds of acorns required				
90 days	225	–	0.9	
365 days	–	40.2	–	
d. pounds of acorns/acre/year	225	20.1	0.18	245

[1] 90 deer days/acre/year also means 1 deer/acre for 90 days of use

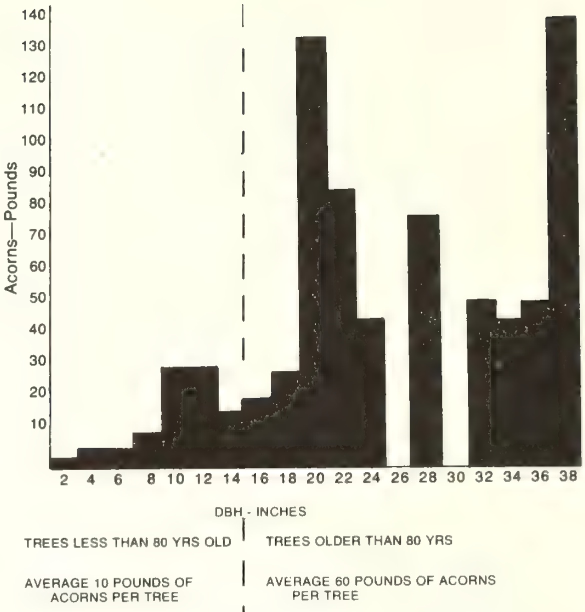
Table 1--Estimated acorn requirements of deer, squirrels and quail.

years, the diet of these and other acorn consumers will shift to other food sources. Sometimes these are inadequate, as winter mortality is strongly correlated with years of low acorn availability.

Once the mast requirements were estimated, the next step was to determine the acorn production of oaks by age class to provide 490 pounds of acorns per acre. Data are extremely limited, although generalizations on expected mast production are available (U.S.F.S. 1969). Perhaps the best data are from a study of California black oaks by Graves (1977) on the Plumas and Tahoe National Forests in 1975 and 1976 (fig.1). Black oaks do not produce large numbers of acorns until they are over 80 years of age, and after 160 years, mast production declines (McDonald 1969). Based on the above studies, a weighted average of 60 pounds (27.2 Kg) acorns per tree was calculated for trees over 80 years old.

STAND STRUCTURE TO MEET MAST REQUIREMENTS

The first step in developing the required stand structure was to determine the amount of area that was to be occupied by oak. Acorn production per tree was the starting point for this determination. Because the Plumas-Tahoe study did not distinguish between acorn production of open-grown trees and those grown in a closed canopy, and because acorn production in this study was not correlated closely with size of tree, two different approaches were taken to determine the basal area of oak needed. Both methods relied on the observations that : (1) trees in the study area older than 80 years generally were 20 inches (54 cm) d.b.h. or larger and (2) at 60 pounds of acorns per tree it would take 8.2 trees per acre to produce the 490 pounds of acorns needed by consumers.



No productive trees were sampled in the 26-inch and 30-inch d.b.h. classes

Figure 1--Estimated number of pounds of fresh California black oak acorns per tree per year as related to diameter at breast height.

First it was estimated that a 20-inch d.b.h. open-grown tree would have a crown diameter of 36 feet (10.9 m)(U.S.F.S. 1969), and 8.2 open grown trees would occupy about 20 percent of each acre. If an equivalent area was added to provide for replacement of acorn producers by trees in the 0-80 year age class, then 40 percent of the area would be occupied by oak.

The second approach multiplied the basal area of a 20-inch d.b.h. tree by 8.2 trees to arrive at a basal area of 18 square feet per acre (4.1 m^2/ha) needed in trees 80 years and older (2.18 ft^2/tree x 8.2 trees/ac.=18 ft^2/acre) This figure was compared to the levels tentatively recommended for oak stands on above average sites of 120 ft^2/acre (27.6 m^2/ha) (Tappeiner and McDonald 1979) and found to be about 15 percent. The assumption was then made that in a well-stocked oak stand older than 80 years, about 15 percent of the surface area would be occupied by crowns. This figure was doubled to provide for replacement by the 0-80 year age class. The result was that 30% of the area would be occupied by oak.

Using these approaches then, the range seemed to be 30-40 percent of the area would be occupied by oak, and this was established as a guideline.

SPATIAL ARRANGEMENTS

The next step was to define an arrangement of oaks and conifers on the ground that could be used for practical management purposes. Oaks in association with conifers on the Stanislaus occur as single individuals, in pure aggregations of 0.1 to 1 acre (0.04 to 0.40 ha), or occasionally in small stands of 2 to 3 acres (0.8 to 1.2 ha). Aggregations are small homogeneous units of oak in conifer stands. The main criterion used to identify oak aggregations was at least 80 percent crown cover in oak. Canyon live oaks also occur in significant number on the Stanislaus herd winter range. Where the two species occur together, both will be managed under these guidelines.

On south slopes oak occurs primarily as aggregations. It seemed reasonable to retain uniformly distributed oak aggregations because these aggregations are easily recognized on the ground by field crews, and because they are more efficiently managed than single trees. Thus, the guidelines picture conifer-oak stands with a 30 to 40 percent oak component distributed as uniformly as possible in aggregations of 0.1 to 1 acre in size (fig. 2). The remaining area would be occupied by conifers. The oak aggregations should occur in roughly 2 age groups of 0 to 80 years and 80 to 160 years with a stocking level of 18 square feet per acre in the 80 to 160 year age group.

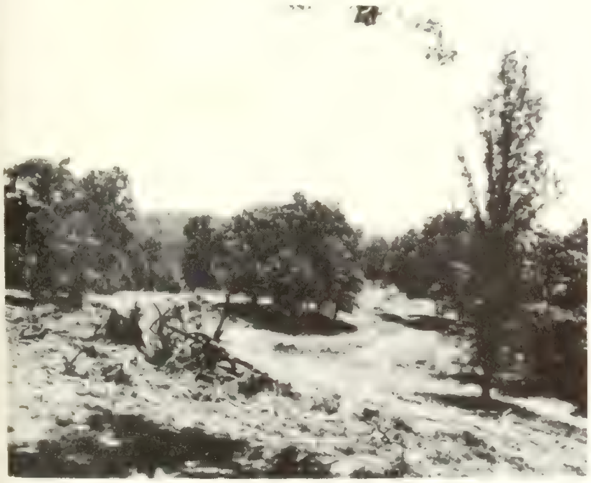


Figure 2--Area prepared for conifer plantation with black oak aggregations retained.

On north slopes current Forest Service Region 5 guidelines for hardwood retention will be used. They specify 5 square feet of basal area per acre. If this is doubled to account for two age classes, it amounts to over 8 percent of a well-stocked oak stand for these sites. Individual trees or aggregations could be used on these slopes.

To maintain oaks in aggregations that consistently produce mast will require considerable effort. Better acorn production data are needed by site, age, species, and stocking density. For example, in the 1975 study of 110 black oaks on the Tahoe and Plumas National Forest, 20 percent of the sample consisted of non-acorn-producing oaks (Barrett and Menke 3/). Regeneration of California black oak by planting has never been seriously undertaken in California. If regeneration is established either naturally or artifically, protection of young seedlings from damage by deer will undoubtedly be necessary. Once young oak aggregations are established, thinning probably will be necessary to develop full-crowned mast producers.

IMPLEMENTATION OF GUIDELINES

Four steps were followed for applying the oak guidelines to large units of the winter range.

Step 1. The angle of the winter sun was determined and the slopes receiving the most winter sunlight, were identified on a topographic map.

Step 2. An overlay showing the location and acreage of accessible commercial timber lands was prepared. Those lands falling on southerly slopes were identified for 30-40% oak retention.

Step 3. Using aerial photos, an overlay of timber types was prepared. Stands were divided into ten acre grids and the oak component was shaded by 3 classes of 0 to 20 percent, 20 to 50 percent and greater than 50 percent. This enabled us to ascertain the levels of oak stocking by stands, over the total compartment, relative to our stocking guidelines,and to select specific stands for treatment on a priority basis.

DISCUSSION

This analysis would not be complete without discussing its effects on timber production. There are adequate predictions of conifer yields for California forest lands (Dunning and Reineke 1933). There is little doubt that conifer yields will decrease using the proposed guidelines.

However, using the management techniques developed here and the existing timber yield data, the impact of different deer population objectives can be evaluated by the land manager. In this way, a desired balance between timber and deer production can be achieved where both resources occur in the same area.

Oaks could yield a positive timber return in the near future. At present, oak is used primarily for fuel wood on the Stanislaus, and it does not constitute a part of the regulated forest yield. Throughout the rest of the world this is not the case, where foresters look at yields of both conifers and hardwoods. Maintaining oaks up to 160 years will likely produce some high quality hardwood, and this would increase the value of the timber yield substantially.

Quantification of deer population response to various levels of oak retention is not easily displayed for the decisionmaker. Although deer numbers and acorn availability probably do not form a direct linear relationship, we can safely assume that increased acorn yields from managed oakstands will greatly increase the size, health, and stability of the Stanislaus deer herd.

These guidelines were developed for a specific management problem on the Stanislaus deer winter range. However, we feel the approach can be applied to other vegetation complexes and other wildlife species.

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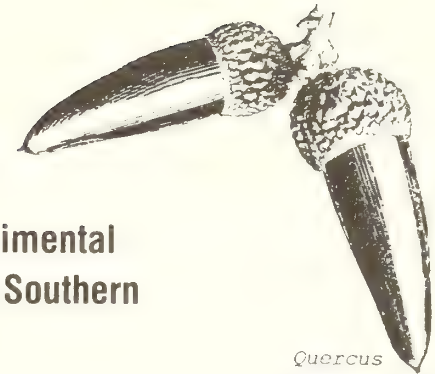
Quercus lobata

Oak Management Harvest A: An Experimental Management and Utilization Project on Southern California Private Ownership[1]

James E. Asher, A.C.F.[2]

Abstract: A large-acreage, corporate landowner has instituted a comprehensive, long-range, forest management program on its multiple-use wildlands under this Consulting Forester; the Plan ultimately includes bringing a sizeable mixed hardwood resource under management. In early 1979 we began: (1) a formal hardwood inventory of 7,680 acres (First Increment-Classification and Inventory), and (2) a 300-acre working "demonstration" oak management forest operation (Oak Management Harvest A) with all harvested material to be utilized in the Ranch ongoing program.

INTRODUCTION

Tejon Ranch consists of two hundred seventy thousand acres forming the largest contiguous Spanish land grant holdings in California and is the setting for this report. The Tejon Ranch Company, a farsighted landowner, is engaged in diversified agriculture, and produces many crops ranging from cotton to pistachio nuts on its flat lowlands in the San Joaquin and Antelope Valleys, where the elevation ranges from one hundred to three thousand feet. Tejon Ranch contains working, non-renewable resources including oil and mineral leases and even a cement plant. A Tejon Ranch mainstay is its Livestock Division, historically running ten to fifteen thousand head of cattle on its ranges that go up to 6,700 feet in elevation. Because of its awareness of renewable natural resources, the Tejon Ranch instituted wildlife management over thirty years ago. Beneficial and profitable controlled recreational hunting of deer, small game, and birds has helped to nurture heavy and healthy game populations.

In 1975 Tejon Ranch Company agreed with the Consulting Forester on the desirability of long-range forest management whereby the forest and other resources could be improved. The forest had the potential of contributing much more to the ongoing corporate picture under planned utilization and not at the expense of the other natural resources and Ranch uses; in fact,sustaining forestry would enhance all other values.

Softwood forest management, begun on a forest condition priority basis, soon made evident the needs and the potentials of the Ranch hardwood forest. Considerable acreage was found to support Upper Sonoran and Transition life zone mixed oak stands. Densest on northern exposures and on ridgetops above 4,000 feet is California black oak (Quercus kelloggii). Flats, ridgetops and some sidehills are forested with a "savannah" oak forest composed mostly of blue oak (Quercus douglasii) and California white oak (Quercus lobata). Scattered below 3,000 feet is interior live oak (Quercus wislizenii). Canyon live oak (Quercus chrysolepis) occurs in dense stands on north slopes at middle and upper levels. Antelope-San Joaquin Divide ridge country, along the higher summits, contains approximately 15,000 acres of dense, shrubby Brewer's oak (Quercus garryana var.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, June 27, 1979, Claremont, California.

[2] Consulting Forester, Lake Arrowhead, California.

breweri). Other hardwood species grow in selected arid to riparian sites, which include the chapparral representative scrub oak (*Quercus dumosa*). A hardwood forest inventory by forest type-delineated acreages is underway but incomplete.

Initial hardwood forest management goals are (1) inventorying of the resource (which today presents many "unknowns"), and (2) commencement of an experiment ("demonstration forest") to (a) begin the development of sound silviculture, and (b) determine the economic feasibilities.

In keeping with the necessary sound corporate approach for such a long term endeavor, the establishment of markets for oak wood products to finance the management of oak woodlands is paramount. For the Tejon Ranch Company, until financially feasible markets are found and secured, no comprehensive forest management planning and activity is practical (affordable). "Oak Management Harvest A" is a start toward these initial goals. The project is a test harvest and product manufacturing effort to develop techniques and establish their costs and to place various kinds of materials into potential market channels; it is important also to put practical meaning into the evolving hardwood forest inventory.

"Oak Management Harvest A" involved 300 acres of oak types within a 1,500-acre area in the Bear Trap Canyon section of Tejon Ranch. It was administered as a Tejon Ranch timber sale under standard controls and constraints. A logging operator was contracted to harvest and mill a variety of species and products. A portable sawmill was installed in the timber sale area which produced 30,000 bd. ft. of oak lumber (rough, green) grading from Number three common (pallet stock) up through Number one common and better (furniture grades). Along with the lumber, 100,000 bd. ft. of logs, in variety, were prepared for direct shipments. The attempt is being made to inject these materials into all possible markets across the United States and overseas.

The expected market resistance is being encountered with these "unproven" California oaks; only long-standing traditional hardwood supply sources are trusted. Meanwhile, we are waiting for information from certain markets cooperating in testing the Tejon Ranch lumber and logs.

Key in gaining interest from and limited access to the cooperating hardwood consumers is (1) that a significant volume of oak resource is available on a continuing basis, and (2) that the Tejon Ranch Company has a resource-oriented and long-range policy of managed utilization of its assets, thus providing a potential of continuing sustained production of forest values including wood products. The selection of sample materials for the market search is deliberately varied, and consistently includes some materials of the highest quality. It is felt that a target of high per-unit monetary return must be obtained from the high-quality material to sustain a successful Program because the greater proportion of lesser quality products can and will be disposed of at lower profits. "Oak Management Harvest A" must show that oak forest management will pay for itself or the concept cannot be considered feasible and be continued. Indications from one buyer are that a satisfactory recovery of high grade lumber is possible provided that it is (1) milled properly for grade and at correct and consistent dimension, and (2) is carefully cured under exacting conditions (introducing some critical "unknowns"). This very preliminary reaction is encouraging though indicative of the time and effort needed to develop the project to feasibility.

Silviculture is being developed with the input of several interested agencies such as the California Department of Forestry, the California Department of Fish and Game, Kern County Fire Department. Thinning from below, aimed at a level of stocking control effective in meeting the multiple-use guidelines of Tejon Ranch natural resource management is being applied along with an "oak sanitation-salvage" approach. Crown dieback is the principal indicator being used to rate "risk" oaks. A very light cut is resulting to date in applying this prescription combination; compatible with the heavy Ranch emphasis on continuing aesthetic value.

CONCLUSION

"Oak Management Harvest A"; brought to light several problems such as high harvesting, milling, and curing costs; is in its completion stage. A major problem is the slash and debris accumulation; fuelwood contractors have been brought in to accomplish cleanup on the Project. Evaluation of the results of the silvicultural prescriptions is being done; time will be needed, particularly to assess effects upon the regeneration problem. Cattle and deer exclosures and other measures are to be installed on sample areas to further refine project effects. Market suitability of the oaks, the vital factor, has yet to be interpreted and returned by the cooperating purchasers.

Quercus kelloggii

Growth of Thinned and Unthinned Hardwood Stands in the Northern Sierra Nevada . . . Preliminary Findings[1]

Philip M. McDonald[2]

Abstract: Sixty-year-old stands of California black oak, tanoak, and Pacific madrone were thinned from a basal area of 198 ft^2/acre to 85 to 141 ft^2/acre, and their responses evaluated. Diameter growth of the three species doubled after 8 years and when averaged, increased from 0.46 to 0.98 inch. Larger trees and dominant trees grew best. Diameter growth of trees in clumps containing up to four members was equal to that of single stems of the same diameter. Average annual cubic volume growth of thinned stands ranged from 66 to almost 89 ft^3/acre/year. Results are preliminary and any conclusions drawn from them are speculative.

INTRODUCTION

Among the hardwood tree species in California, tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), California black oak (*Quercus kelloggii* Newb.), and Pacific madrone (*Arbutus menziesii* Pursh) show the most promise for providing wood products, fuel, and fiber. In northern and, to a lesser extent, central California, these species are extensive and abundant. In 1975, volumes estimated for California were about 2.55 billion board feet (14.5 million m^3) of California black oak, 1.97 billion board feet (11.2 million m^3) of tanoak, and 0.98 billion board feet (5.5 million m^3) of Pacific madrone sawtimber.[3]

These hardwood species are found growing singly, in small aggregations, or occasionally covering an entire hillside. In many instances, they are the stepchildren of disturbance. Heavy logging or fire reduces conifer competition and allows them to grow more freely. All have strong sprouting ability and, even if killed above ground, usually remain viable below. Extensive and rapidly-growing sprouts quickly occupy and often take over disturbed areas.

Because fire has been commonplace in the Sierra Nevada since the 1850's, nearly all hardwood stands are of sprout origin. Some single trees show multiple centers when cut--presenting evidence of former clumpiness. Because original stands often were dense to begin with, and rendered more so because of multiple sprouts, young-growth stands also tend to be dense. Tree growth is slow and often decreases until mortality provides growing space for survivors.

Some landowners are asking questions on how to manage their hardwood resources. "What amount of yield can I expect," and "What is the best spacing and thinning regime to maximize growth and yield" are the two questions most frequently asked. Little information is available, with almost none that quantifies the growth response to stand manipulation.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks. Claremont, California, June 26-28, 1979.

[2] Research Forester, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Redding, California.

[3] Personal communication from Charles L. Bolsinger, Forest Service, U.S. Department of Agriculture, Portland, Oregon, August 1978.

This paper presents stand response information. As such, it is an attempt to fill a critical gap in the management of these species of native California hardwoods. Results provided are tentative. They represent only a portion of a larger study, do not have enough duration to establish firm trends, and are not statistically verified. They are presented to show what is being attempted and to quantify relationships to date. Any conclusions drawn from them are speculative and given only to provide an idea of "what might be."

THE STUDY

The setting for this study is the Challenge Experimental Forest, Yuba County, California, from 1968 to 1978. Here young-growth stands of California black oak, tanoak, and Pacific madrone are commonplace. The stands tend to be even-aged, originating from sprouts after fire or disturbance. In 1968, stand age was about 60 years.

Site quality of the Experimental Forest is high. Dominant California black oaks are about 70 feet tall at age 60--indicating site index to be 60 at a reference age of 50 years (Powers 1972). The soil is deep and fertile, the mean annual temperature is 55°F (13°C), and precipitation averages 68 inches (1727 mm) per year.

To quantify the growth of individual species as well as that for mixed hardwood stands, 14 ¼-acre (0.1-ha) circular plots were established. They ranged from 60 to 150 ft^2/acre of basal area. Somewhere within this range would be a basal area that would balance the level of growing stock with the most efficient use of available resources, and therefore, maximize growth. One plot was selected randomly as an uncut control. Prescribed basal areas were assigned randomly to the others.

Lack of knowledge on hardwood growth response in general, and a probable need to establish a wide range of basal area levels, each with several replications, suggested that some form of replicated experimental design be used. Lack of enough homogeneous area to establish the large number of anticipated plots, however, plus difficulty in getting the stands thinned at the same time, mandated that a different and, perhaps, more exploratory approach be used. One plot for each prescribed basal area was established. Statistical analysis of growth response was to be by multiple regression.

Marking guides were difficult to formulate. Leaning trees are common, particularly of California black oak, therefore, clumps can occupy one piece of ground and their crowns influence another. After the stand was marked to the prescribed basal area, crown thinning provided residual trees with "sky light" or room to expand. Straight, tall, thrifty, well-formed trees were favored (fig. 1). No more than four stems per clump were allowed because additional stems often were of poor form (fig. 2). Each plot was surrounded with a buffer zone, 20 to 60 feet (6 to 18 m) wide, cut to its prescribed basal area.

Local fuelwood cutters thinned the stand in return for the wood. Cutting rules required removal of all unmarked trees, stumps no higher than 8 inches (20 cm) above mean ground line, and the piling of slash. Utilization of the trees was to a 2-inch (5-cm) top.

In each growth plot, all leave trees larger than 3.5 inches (9 cm) in diameter were numbered 2 inches (5 cm) above breast height. Tree species, diameter, crown class, and clump density (one to four members per clump) were recorded annually. Diameter growth was calculated first as basal area, averaged, and converted to a diameter basis. Cubic volumes to a total top were taken from volume tables applicable to each species on high sites (McDonald 1978). Six plots with prescribed basal areas of 85 to 141 ft^2/acre (20 to 32 m^2/ha), and the control with 209 ft^2/acre (48 m^2/ha) had data spanning 8 years (table 1). These plots are the basis for this report. The seven other growth plots were thinned at a later date and, therefore, had a shorter period of data collection. Statistical analysis, however, was not possible until sufficient data had accrued for all 14 plots.

RESULTS

Unthinned Stands

Data from the six ¼-acre growth plots and control indicated that basal area of the unthinned 60-year-old stands ranged from 165 to 230 ft^2/acre (38 to 53 m^2/ha). As a composite stand, they averaged 198 ft^2/acre (46 m^2/ha) and 659 stems per acre (1628 stems/ha) in the range of 2 to more than 16 inches (5 to more than 41 cm) in diameter at breast height. Number of stems ranged from 832 to 416 per acre (2056 to 1028/ha) and were typical of unthinned hardwood stands of these species in this area. Although these values indicate prethinning diversity, they also indicate that stands were quite dense and growing slowly. To compare thinned and unthinned stands, those that were thinned were combined and averaged to form a composite stand (plot). They are not strictly combinable, however, and will be treated independently in future regression analyses.

For the composite plot, about 57 percent of the total stems fell into the 4.1- to 8.0-inch (10- to 20-cm) diameter class, 27 percent into the 8.1- to 12.0-inch (21- to 31-cm) class, with the remainder either larger or smaller. In terms of species composition, tanoak contributed 63 percent of the total number of stems, California black oak 23 percent, and Pacific madrone the remaining 14 percent. The stands contained about 4090 ft^3 or nearly 43 cords of wood per acre (274 m^3/ha) when utilized to a 2-inch (5-cm) top.

Thinned Stands

An examination of cut stumps indicated that tree vigor generally had been poor. Trees averaged 12 to 15 growth rings per inch of diameter (5 to 6 rings/cm) with the annual growth rate in slow decline.

Thinning reduced the composite plot basal area by 41 percent and the number of stems per acre by nearly 70 percent. All stems less than 4 inches (10 cm) d.b.h. were eliminated and those in the 4.1- to 8-inch (11- to 20-cm) class were reduced by 77 percent. Tanoak was cut heavily and a more equitable mix of species was achieved.

Thinning also increased the proportion of trees with more fully developed crowns. When calculated as a percentage of the composite stand, the proportion of trees in the codominant crown class doubled; and in the dominant class, tripled. After thinning, trees in these two classes constituted 79 percent of all trees. Also, average stand diameter was increased by thinning, especially for tanoak and, to a lesser extent, for California black oak and Pacific madrone.

A total of almost 700 trees were removed from the growth plots. No heart rot was observed in the stumps. Young-growth trees of these species, either from seed or root crowns, are usually free of this malady, at least in this area.

Mortality during the 8-year timespan was low in the thinned plots. One to five trees died in each plot--18 trees died altogether. The most common cause of death to tanoak and Pacific madrone apparently was disease (blight); for California black oak, suppression, and too much shade in the still too-dense plots often led to mortality. Natural mortality during 8 years in the uncut control was 14 percent or more than twice that of the thinned plots. Most of the trees that died in the control were small California black oaks less than 5 inches (13 cm) d.b.h. Suppression was the prime cause of death.

Diameter Growth

Among species, tanoak had the best overall diameter growth in both thinned plots and control. Pacific madrone and California black oak followed in decreasing order (table 2). As expected, large trees with wide crowns and large photosynthetic areas grew best. For example, tanoak and California black oak more than 12 inches (30 cm) in diameter at breast height had the largest diameter increases for the 8-year period. Small trees, however, responded most, relative to the control. In the 4.1- to 8.0-inch (10- to 20-cm) diameter class, madrone trees in the thinned plots outgrew those in the control by more than three times; tanoak trees by more than two times. Overall, diameter growth of each species in the thinned plots was more than twice that of each species in the control.

When analyzed further by crown classes, diameter growth in inches per tree, for 8 years, generally decreased as position in the stand declined (table 3). For all species, both in thinned plots and control, dominant trees grew best followed by codominant, intermediate, and suppressed. When diameter growth for all crown classes and species in thinned plots and control was compared by t-test, it was found to be significantly better in the thinned plots ($p = .01$) than in the control.

The growth response to thinning of single trees as compared with thinning of trees in clumps needs to be evaluated. A forest manager needs to know whether or not leaving clumps of trees will decrease total stand growth.

Diameter growth for single stems and clumps having up to four members was determined for the composite thinned stand and for the control (table 4). No trends in diameter growth by species or by number of stems per clump developed during the 8-year study. One reason for the lack of trends was the wide range in diameter of stems within individual clumps.

The relationship between original stem diameters, number of stems in a clump, and stem diameter growth was inconsistent. Growth of individual members of two- and three-member clumps of tanoak and California black oak were averaged for diameter growth each year for 8 years. For three-member California black oak clumps, the initially largest members grew more slowly than other members at first, then at a medium rate, and were most rapidly adding girth to their boles at the end of the study period (fig. 3). The initially smallest members of the

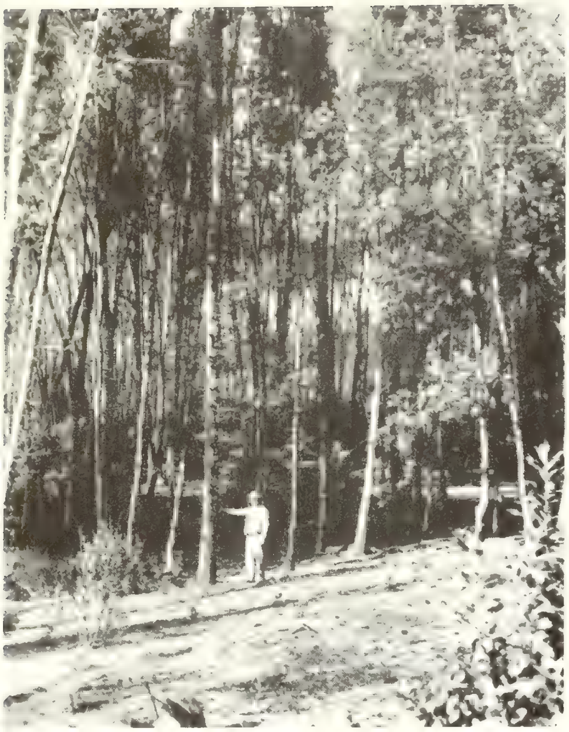

Figure 1--Stands of California black oak, tanoak, and Pacific madrone trees on the Challenge Experimental Forest tend to be even-aged, originating from sprouts after fire or disturbance.

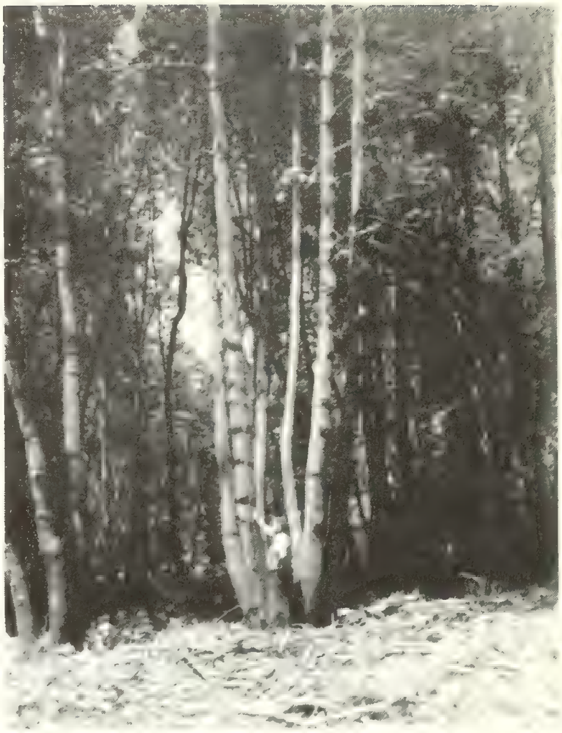

Figure 2--Tanoak clumps of sprout origin often contain trees of both good and poor form.

Table 1--Basal area of sample plots before and after thinning on the Challenge Experimental Forest

Plot	Basal area per acre before thinning	Basal area per acre after thinning	Reduction
	Ft^2	Ft^2	Percent
1	165	102	38
2	194	110	44
3	208	125	40
5	230	141	39
6	206	136	34
7	188	85	55
Average	198	116	41
Control	209	209	0

Table 2--Comparative diameter growth in thinned plots (T) and control (C) by species and diameter class during an 8-year study on the Challenge Experimental Forest

Species	8-year diameter growth by diameter class									
	4.1 to 8.0		8.1 to 12.0		12.1 to 16.0		16.1 to 20.0		All sizes	
	T	C	T	C	T	C	T	C	T	C
	Inches/tree									
Pacific madrone	0.58	0.15	0.83	0.48	1.09	1.02	----[1]	----	0.87	0.40
Tanoak	.93	.45	1.19	.87	1.29	1.35	1.25	----	1.18	.63
California black oak	.50	.32	.80	.65	1.27	----	----	----	.74	.38
All species	.64	.33	.99	.69	1.25	1.13	1.25	----	.98	.46

[1] Dashes indicate no trees present.

Table 3--Relationship of diameter growth to crown class in thinned plots and control for an 8-year study on the Challenge Experimental Forest

Species	Crown class	8-year diameter growth	
		Thinned plots	Control
		--Inches/tree--	
Pacific madrone	Dominant	1.00	0.87
	Codominant	.90	.55
	Intermediate	.52	.22
	Suppressed	----[1]	.12
Tanoak	Dominant	1.32	1.23
	Codominant	1.13	.67
	Intermediate	1.13	.67
	Suppressed	----	.29
California black oak	Dominant	.96	.60
	Codominant	.72	.35
	Intermediate	.36	.21
	Suppressed	----	.10

[1] Dashes indicate no trees present.

Table 4--Effect of clump density on diameter growth in composite thinned plot (T) and control (C) for an 8-year study on the Challenge Experimental Forest

Species	8-year diameter growth per stem when number of stems per clump was:							
	1		2		3		4	
	T	C	T	C	T	C	T	C
	Inches							
Pacific madrone	0.89	0.36	0.65	0.58	----[1]	0.20	----	0.40
Tanoak	1.19	.78	1.20	.67	1.00	.42	1.25	.68
California black oak	.74	.36	.73	.47	.70	.46	.68	----
Weighted average	.95	.40	1.03	.58	.86	.42	.96	.54

[1] Dashes indicate no clumps present.

Table 5--Diameter growth by species and residual basal area during an 8-year study on the Challenge Experimental Forest

Species	Eight-year diameter growth when basal area (ft^2/acre) was:						
	85	102	110	125	136	141	209
	Inches/tree						
Pacific madrone	0.7	---[1]	1.1	0.8	---	---	0.4
Tanoak	1.4	1.6	1.3	1.1	1.0	1.0	.6
California black oak	1.1	1.0	.8	.8	.6	.6	.3
Weighted average	1.2	1.3	1.1	.9	.9	.7	.4

[1] Dashes indicate no trees present.

Table 6--Average annual and net cubic volume growth for all species combined by residual basal area, for 8-year period

	Residual basal area level (Ft^2)						
	Thinned plots						Control
	85	102	110	125	136	141	209
	Ft^3/acre/yr						
Gross	66.3	87.6	77.2	88.8	70.3	77.6	81.8
Mortality	17.0	3.4	12.0	2.2	15.0	13.3	16.6
Net	49.3	84.2	65.2	86.6	55.3	64.3	65.2

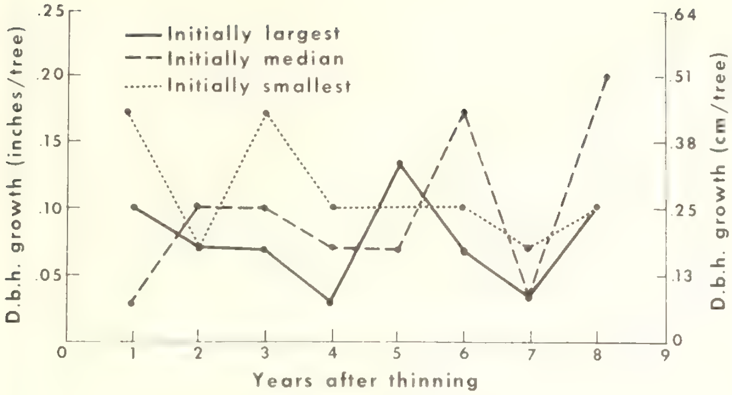

Figure 3--Annual d.b.h. growth of each member in California black oak clumps having three members.

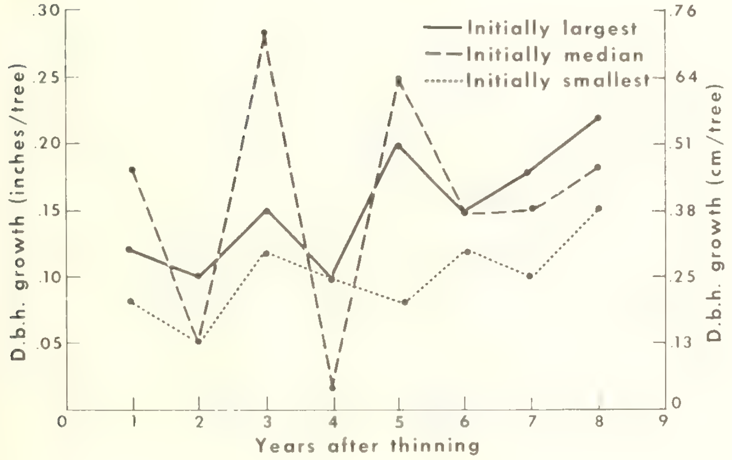

Figure 4--Annual d.b.h. growth of each member in tanoak clumps having three members.

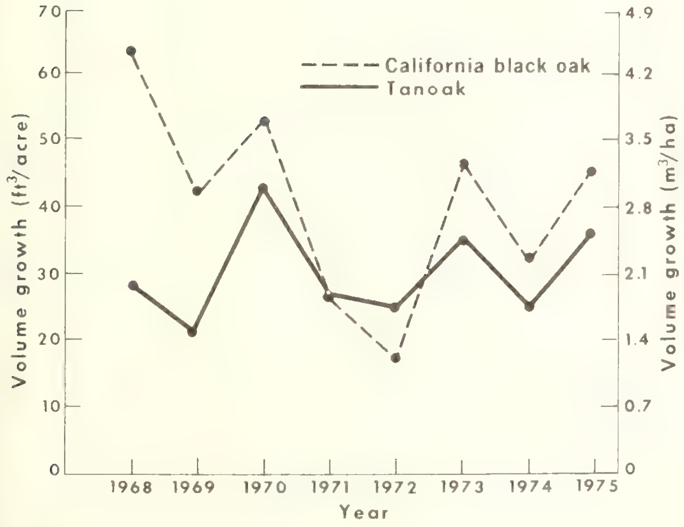

Figure 5--Annual trend of volume growth for California black oak and tanoak in a stand cut to 141 ft^2/acre of basal area.

clumps grew rapidly at first, then moderately throughout. The initially medium-sized members began with a modest diameter growth rate, fell behind, and then increased. For at least 1 year, however, they outgrew the other clump members. For three-member tanoak clumps, the initially largest members generally grew fastest, and the initially smallest members grew slowest (fig. 4). The initially medium-sized members indicated a wide range in annual growth rate--best for 3 years, poorest for 1, and intermediate for 4.

For two-member California black oak and tanoak clumps, the initially largest stems generally outgew the smallest. Differences in annual growth rates between the two members, minimal throughout the study, were even less during the eighth year than the first. A similar analysis was done for four-member clumps. Results from this analysis are not given because the number of clumps of this size was small. Average diameter growth of individual stems in four-member clumps, however, was no less than that for single trees of comparable size.

Analysis of diameter growth for 8 years, by residual basal area density, indicated species and stand response to thinning (table 5). For tanoak, diameter growth ranged from 1.0 to 1.6 inches (2.5 to 4.0 cm) per tree, for Pacific madrone 0.7 to 1.1 inches (1.6 to 2.8 cm). Diameter growth of California black oak ranged from 0.6 to 1.1 inches (1.5 to 2.8 cm) per tree and was progressively lower as residual basal area density increased.

Another means of evaluating stand response to manipulation is by quantifying cubic volume growth. For thinned plots and control, gross cubic volume growth for all species ranged from about 66 to almost 89 ft^3/acre/yr (4.6 to 6.2 m^3/ha/yr) (table 6). Natural mortality reduced average annual or gross growth from 2 to 26 percent. Stand densities of 85 and 209 ft^2/acre (19 and 48 m^2/ha) suffered the highest mortality.

Because diameter growth of California black oak seemed to be declining when basal area density exceeded 125 ft^2 (29 m^2), analysis of data from a representative plot examined this trend more closely. On the basis of available information, the plot having 141 ft^2 (32 m^2) of basal area was considered to be representative, recognizing that it may or may not be typical.

The trend of net cubic volume growth during the 8 years indicated wide variation in growth rate, and for California black oak, a generally declining growth trend (fig. 5). Large declines in rate often resulted from mortality. Tanoak showed less variation than black oak, mostly because of less mortality. Volume growth rate of tanoak appeared to be steady or increasing slightly.

DISCUSSION AND CONCLUSIONS

Limited data and one researcher's subjective thoughts on the biological response of tanoak, California black oak, and Pacific madrone to manipulation are the basis for the statements that follow.

Each of these species occupies a specific niche in the forest and each responds differently to the biological and climatic forces operating there. Tanoak grows fairly well in shady uncut stands and small trees respond well in terms of diameter growth when thinned. California black oak needs more sunlight. Smaller trees grow poorly in the natural stand and almost as poorly in stands thinned to 130 or more ft^2/acre (30 m^2/ha) of basal area.

Tanoak, California black oak, and Pacific madrone respond to thinning. Relative to trees in the unthinned control they doubled in diameter growth. For tanoak, indications are that growth will stay the same or accelerate in the years ahead. For California black oak, an increased growth rate is not certain. Trees in stand densities above 125 ft^2/acre (29 m^2/ha) seem to be declining.

The thinning trial was not replicated, but indicates certain trends. Stands thinned at 102 and 125 ft^2/acre (23 and 29 m^2/ha) grew the most in cubic volume. At basal areas above 125 ft^2 stands have too many stems, a more shady environment and less available moisture--all of which could inhibit the vigor of California black oak. Below 102 ft^2/acre of basal area, stands were too open and seemed to be too warm for tanoak and Pacific madrone. Higher mortality in stands below 102 and above 125 ft^2/ acre, therefore, seems likely.

Net growth from the stands thinned to 102 and 125 ft^2/acre was about 85 ft^3/acre (6 m^3/ha) each year. This is not a bad growth rate in its own right. If it consisted of quality wood from pruned trees, such stands could be economically competitive with conifers. And because these hardwoods in characteristically dense stands prune naturally, pruning costs should be low.

The finding that California black oak and tanoak grow about equally whether as single trees or in clumps of two to four stems, at least for the age of tree in this study, has significance for the forester. It could mean that no penalty of decreased growth will result from leaving clumps of well-formed stems (fig.

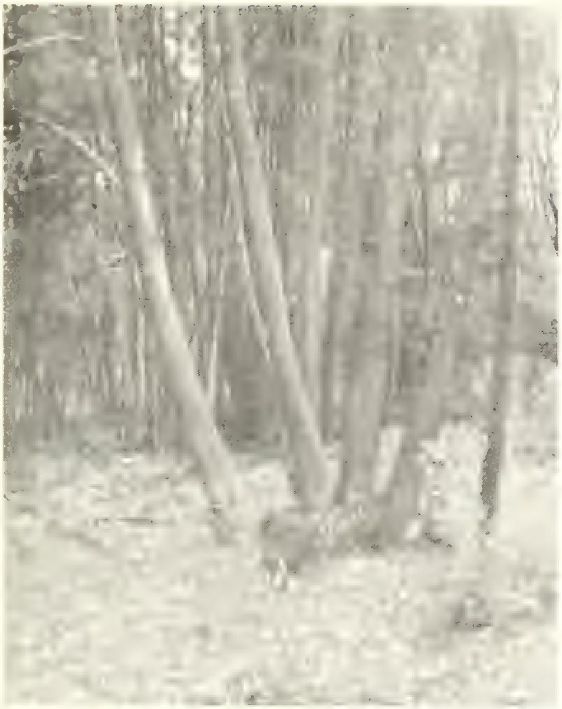

Figure 6--Diameter growth of each member of this thinned clump will be about equal to that of four single trees of comparable size.

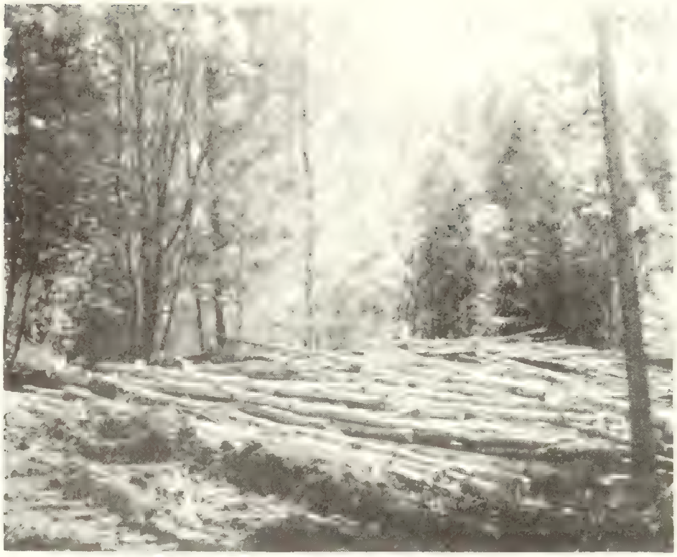

Figure 7--Young-growth hardwood stands in north-central California yield a large volume of wood for product and energy use. Yield is almost 4090 ft^3/acre or 43 cords per acre (274 m^3/ha).

6) for possibly up to 70- to 80-year rotations. Because two to four well-formed members per tanoak and California black oak clump are commonplace in natural stands, foresters are free to leave them, if they wish.

For years, foresters have known that mixed-hardwood stands in the north-central Sierra Nevada contained numerous stems. Perhaps they did not realize how much wood these stands represented. Almost 4090 ft^3 or 43 cords per acre (274 m^3/ha) is a lot of wood (fig. 7). Little of it is rotton. Nearly all trees in the study area originate from root crowns. These structures apparently reduce greatly the incidence of heart rot bridging from rotting stump to pith of sprouts.

These early results indicate that the three species of native California hardwoods studied are rather unusual. They often grow in clumps, growth of 55- to 65-year-old trees is spread adequately over two to four members in each clump, and response to release by thinning is variable. Such findings probably mean that management guidelines specific to native California hardwoods will need to be developed.

The one sure conclusion at present is that we are clarifying what we need to know. Much work, more studies, and more data are necessary before firm guidelines for maximizing growth from native California hardwoods will be available.

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Quercus kelloggii

Radial Growth of California Black Oak in the San Bernardino Mountains[1]

Barbara Gemmill[2]

Abstract: Hypotheses concerning growth of California black oak in the San Bernardino mountains were tested. Black oaks were found to grow radially in a slightly asymmetrical manner. Number of stems per clump decreased with age. Diameter of the largest stem and average radial growth for the previous 60 years increased with number of stems. Growth curves representing expected radial growth of black oaks in the San Bernardino mountains are presented. Possible air pollution effects on black oak radial growth are discussed.

INTRODUCTION

Oxidant air pollutants from the Los Angeles Basin have been affecting the coniferous forests of the San Bernardino mountains to a significant degree since World War II. Symptoms of severe ozone damage to several conifer forest species have been noted. The chlorotic condition of the foliage and rate of needle shedding have suggested that a reduction in growth may be a consequence of high oxidant doses (McBride, Semion and Miller, 1975). A hardwood associate, California black oak (*Quercus kellogii* Newb.), also exhibits symptoms of ozone damage, although not as severely as the conifer species. The radial growth of five coniferous species and California black oak with regard to air pollution in the San Bernardino mountains is currently being investigated as part of the Environmental Protection Agency/San Bernardino National Forest (EPA/SBNF) Ecosystem Project. A preliminary analysis of the black oak portion of the study is reported here.

The impact of photochemical oxidants on black oak radial growth is unknown. In order to assess the magnitude of the likely growth depression brought about by air pollution, more information is needed initially to portray the expected growth of a typical black oak in the San Bernardino population of California black oak. In this analysis, I have tested several suggestions and observations found in the literature relating to black oak growth. It is important to note that since most published information on black oak growth consists of observations and not data, my hypotheses are based on conjecture. Where observations only suggested certain relations, I have taken the liberty of proposing quantitative comparisons for the purpose of testing their possible validity. Also, the analysis is specific to the San Bernardino mountains and cannot be projected to California black oak populations in general at our given state of knowledge. Hypotheses to be tested include:

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[1] Presented at the Symposium on the Ecology, Management and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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(1) Two cores taken from opposite sides of a tree are proportional and represent growth. Standard procedure in the dendrochronology field is to utilize two cores from opposite sides of a tree, perpendicular to the direction of slope to avoid reaction wood (Fritts, 1976). The intention is to minimize variance in order to derive a single value representative of radial growth. This procedure applies to all tree species. It is of interest to know whether or not two cores taken by this method adequately represent growth, given the often asymmetrical growth habit of an oak stem.

(2) Growth rate of the main stem in a multi-stemmed tree decreases with increasing number of stems per clump. McDonald (1969) states that the number of sprouts per clump influences growth. For the purpose of this analysis, we will assume a negative influence. Each stem in a clump may be expected to have growth rates slower than a comparable single-stemmed tree, and proportional to number of stems. As a corollary to this,

(3) Diameter of the main stem decreases with increasing number of stems per clump.

(4) Tree height increases as number of stems per clump increases. Somewhat contradictory to the above statement, Edwards (1957) noted that stumps of large trees often produce many stems of equal dominance along with other stems of lower importance. McDonald (1969) also found that sprout number and vigor increased as cut stump diameter increased up to 20 inches, and that the many-stemmed clumps tended to grow the most vigorously. Vigorous growth and dominance, in both of these observations, probably refers to height. Both of these examples refer to young (i.e. 4-yr-old) sprouts. However, since height is an important variable in competitive interactions, it is worthwhile to test whether this relationship is maintained among mature trees.

(5) Number of stems per clump decreases with age of the clone. McDonald (1969) found the number of sprouts per clump to decrease exponentially with age, from approximately 4 sprouts at age 20 to 2 at age 80 and 1 at age 120, based on observations of black oak growing throughout California.

(6) Number of stems per clump increases with decreasing site quality. While initial numbers of sprouts may be related to size and vigor of the parent tree, greater sprout retention and more stems per clump at a given age have been observed on poorer sites (McDonald, 1969).

(7) The shape of generalized radial growth curve for black oak will vary according to site factors, with variance seen in both the location of the peak and the average growth rate.

The intention of this preliminary analysis is to establish which factors relate directly to the prediction of radial growth. The data used for this portion of the analysis should be free from effects of air pollution. At the end of this paper, a discussion of air pollution effects on oak radial growth will be presented, in light of information developed about expected black oak growth in the San Bernardino mountains.

MATERIALS AND METHODS

Black oaks were examined on six vegetation plots forming a portion of the study area of the EPA/SBNF Ecosystem Project. All plots occurred within the conifer forest zone (Horton, 1960) and were dominated by either Ponderosa pine (*Pinus ponderosa* Laws) or Jeffrey pine (*Pinus jeffreyi* Grev. and Balf.). Species composition of the forest overstory is listed in Table 1. Plots varied in length from 100 to 300 meters, with uniform widths of 30 meters, and were located on variable slopes and aspects. Plots extended in length until 80 Ponderosa or Jeffrey pine of dbh greater than 10 cm were included. Site characteristics and location of the plots are described in Table 2 and Figure 1 respectively. The first four plots form a transect from the Crestline area (high pollution levels, low elevation, relatively high precipitation) to Green Valley (lower pollution, higher and drier). The last two plots form part of a similar transect in the Barton Flats area.

In the late summer of 1977, black oaks greater than 10 cm dbh (diameter at breast height) on the six study plots were cored with a Swedish increment borer. Two cores were taken at a height of 1.5 m on opposite sides of each tree through a diameter running perpendicular to the direction of slope. The cores were returned to the laboratory, dried and mounted in wooden holders with the vessel elements running vertically. Sanding tended to clog the pores with sawdust and reduce visibility; consequently, cores were surfaced with a razor blade. Cores were aged and growth rings were measured to the nearest 0.01 mm back to and including the year 1920, using a Henson dendrochronometer.

Data utilized from other portions of the EPA/SBNF study include: height, diameter and number of stems. Site indices for black oak

Table 1--*Percent species composition of the study plots*

	Breezy Point	Camp O-ongo	Deer Lick	Green Valley Creek	Schneider Creek	Camp Osecola
Quercus kellogii	23.0	35.8	28.7	40.2	23.7	10.7
Libocedrus decurrens	22.2	2.8	0.0	4.9	7.7	0.0
Pinus jeffreyi	0.0	0.0	25.2	10.5	0.0	65.1
Pinus ponderosa	53.3	42.2	7.7	7.8	32.1	19.5
Quercus chrysolepsis	1.5	0.0	0.0	0.8	16.7	0.0
Pinus lambertiana	0.0	0.9	16.1	5.4	1.3	0.0
Abies concolor	0.0	18.3	22.4	29.9	25.6	4.7

Table 2--*Site characteristics of the study plots*

	Breezy Point	Camp O-ongo	Deer Lick	Green Valley Creek	Schneider Creek	Camp Osecola
No. trees	115	121	160	228	155	147
Density, trees/acre	155	96	108	102	86	124
Slope, percent	20	25	<5	30	20-45	<5
Aspect	N,NW	N	-	W	N	-
Elevation, feet	5000	6300	6300	6400	6000	7000
Average potential soil rooting depth, m	4.75	4.31	1.09	3.74	7.16	5.64

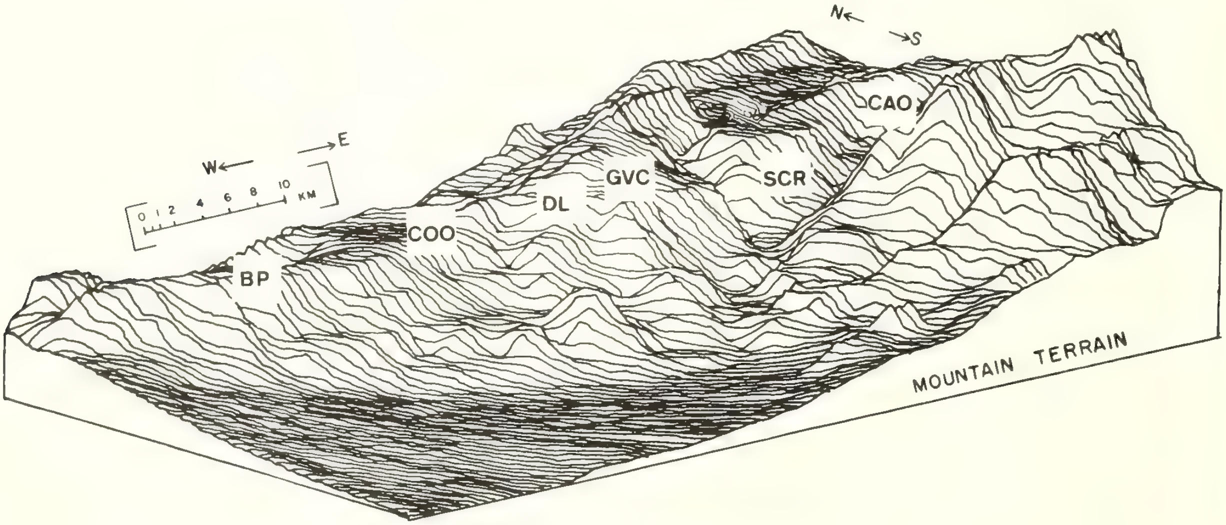

Figure 1--*Location of the study plots in the San Bernardino mountains (BP = Breezy Point, COO = Camp O-ongo, DL = Deer Lick, GVC = Green Valley Creek, SCR = Schneider Creek, CAO = Camp Osceola)* were calculated using the procedure of Powers (1972), in which actual height is compared with expected height at a given age to evaluate growth potential of the site.

Ring widths corresponding to the same year on cores taken from opposite sides of the same tree were correlated using the Pearson correlation procedure (Nie, et al., 1975). Age at breast height, height, diameter, average radial growth and site index were analyzed individually and in combinations against number of stems, by analysis of variance and multiple regression procedures. A generalized growth curve was derived for each separate plot by calculating the age at breast height of the tree at the time each growth ring was formed, and combining ring widths for each age from year 0 to the oldest age of any tree on the plot.

RESULTS AND DISCUSSION

Radial Growth Within Trees

Average correlation coefficients per plot between cores taken from opposite sides of the same tree are presented in Table 3.

Table 3--*Average correlation coefficients, derived by comparing ring growth in sample cores taken from the opposite sides of a single black oak.*

Plot name	Sample size	Average correlation coefficient
Breezy Point	8	.610
Camp O-ongo	38	.686
Deer Lick	15	.428
Green Valley Creek	9	.694
Schneider Creek	27	.578
Camp Osceola	7	.490
Average of all trees	104	.602

The correlation is less than could be expected in arid-site conifers (Fritts, 1976) and suggests that two cores, while they may still provide an estimate of growth, are not consistently proportional to one another. In general, most trees correlated fairly well between cores, with a few extremely poor correlations bringing averages down. Poorest correlations were found among the older trees with very thin growth rings of all the same general magnitude; small variances in such small rings will contribute to a poor correlation. Trees with crooked and leaning growth habits also tended to have weaker correlations.

Predictors of Number of Stems, Radial Growth and Tree Height

For purposes of testing hypotheses 2-6 as outlined in the introduction, number of stems were regressed against other descriptive variables of diameter, height, site index, average radial growth and age at breast height. Additionally, two other dependent variables namely average radial growth and tree height were regressed against the remaining independent variables. Results of the regression are indicated in Table 4. A breakdown of the data into charts is presented in Figure 2.

In the San Bernardino mountains, increasing number of stems correlate positively to the diameter of the largest stem and the average radial growth rate. Number of stems does appear to decrease with increasing age, although the relationship is not strong.

The apparent increase in diameter and growth rate with number of stems, which is contrary to hypothesized results, appears to result from a third relationship: that number of stems, in this area, increase with site quality. Such an increase may well be due to the younger ages of all trees in plots with high site indices, having no older trees to provide controls for age. However, even within one plot, i.e. Camp O-ongo, average growth rates and diameter of the main stem increase with number of stems up to 4 stems per clump. Perhaps these data affirm McDonald's (1968) observations that stumps from larger trees produce both a larger number of sprouts and more vigorous ones. In general, hypotheses relating diameter and site quality to number of stems can neither be upheld nor rejected with a large degree of certainty. However, the fact that the poor sites had almost exclusively single-stemmed trees casts doubt on the statement that, for this area, sprout retention is increased on poorer sites.

Age, diameter of the main stem, tree height, site index and average radial growth for the previous 60 years are all significantly related to number of stems per clump, age negatively and the remainder positively. Average radial growth has very strong correlations with height, age and site index, while height has a strong correlation with diameter. From this analysis, number of stems does not appear to be highly important predictor of average radial growth, although a significant relationship exists. Within a tree, many other relationships are stronger and more consistent.

Table 4--*Calculated f-values for each variable*[1], *all plots*

dependent variable	independent variable	direction of correlation	f-value	significance
number of stems per clump	average diameter, all stems	-	.01	--
	average radial growth, previous 10 years	+	.85	--
	age and average radial growth	-,+	3.00	*[2]
	age	-	3.62	*
	diameter, main stem	+	4.83	**
	height	+	5.16	**
	site index	+	5.63	**
	average radial growth, previous 60 years	+	5.84	**
average radial growth, previous 60 years	diameter, main stem	+	3.89	*
	height	+	47.70	***
	age	-	90.50	***
	site index and age	+	131.58	***
	site index	+	154.70	***
height	age	--	.47	--
	diameter, main stem	+	66.76	***

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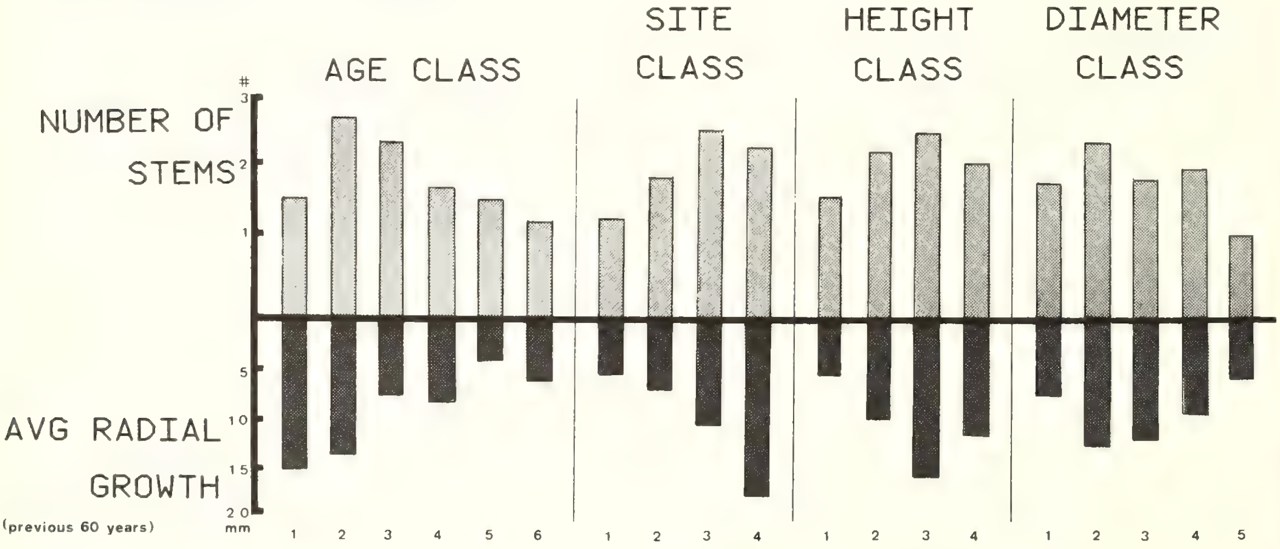
[1] All variables refer to measurements on largest stem in the clump, unless otherwise noted.

[2] * significant at P = 0.10 level
** significant at P = 0.05 level
*** significant at P = 0.01 level



Age classes: 1- 0 years through 60 years; 2- 61 years through 80 years; 3- 81 years through 100 years; 4- 101 years through 120 years; 5- 121 years through 140 years; 6- 140 years and above.
Site classes: 1- 0.0 site index value through 20.0 site index value; 2- 20.1 site index value through 30.0 site index value;3- 30.1 site index value through 40.0 site index value; 4- 40.0 site index value and above.
Height classes: 1- 0.0 meters through 10.0 meters; 2- 10.1 meters through 15.0 meters; 3- 15.1 meters through 20.0 meters; 4- 20.1 meters and above.
Diameter classes: 1- 0.0 cm d.b.h. through 20.0 cm d.b.h.; 2- 20.1 cm d.b.h. through 30.0 cm d.b.h.; 3- 30.1 cm d.b.h. through 40.0 cm d.b.h.; 4- 40.1 cm d.b.h. through 50.0 cm d.b.h.; 5- 50.1 cm d.b.h. and above.

Figure 2--*Breakdown of data into variable classes, all plots. The average value of two dependent variables corresponding to classes of the independent variable is presented.*

Expected Radial Growth Curves

Curves representing typical radial growth of black oak within each of the study plots are presented in Figures 3-4. Since data from different calendar years have been pooled in deriving the curves, responses relating to environmental variables such as yearly fluctuations in precipitation, temperature and air pollution are assumed to balance out, while the expression of long-term site conditions (i.e., soil factors, gradients of average annual precipitation) remain.

Most notable features of these growth curves are the large early radial growth of oaks on higher average rainfall sites (i.e. Breezy Point and Camp O-ongo), and the small but consistent radial growth of old oaks on all sites.

Air Pollution Effects on Radial Growth

Air pollution may be thought of essentially as a defoliator, reducing viable leaf area especially in late summer (see Miller, these proceedings). Other oak defoliation studies, generally concerning eastern North American oaks, have noted that the degree of growth reduction due to defoliation depends on the extent, season and frequency with which the defoliation takes place. Rexrode (1971) noted that severe injury in one year reduced wood production, while successive annual defoliations led to branch dying and tree mortality. Nichols (1968) found that one year of moderate defoliation may reduce radial growth 20 to 30 percent, while one year of heavy defoliation may cause a growth reduction of 40 to 70 percent. Two consecutive years of 60 to 100 percent spring defoliation caused mortality. In contrast, Baker (1941) found that growth increment among oaks 81 to 100 percent defoliated was reduced only one-half of normal.

Air pollution defoliates black oak only moderately, and chiefly in the late summer, rather than during periods of rapid spring growth. Being deciduous there are no direct carryover effects on the foliage from one year to the next. However, it is conceivable

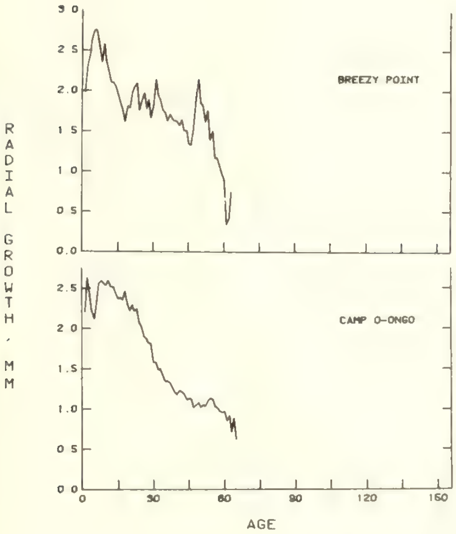


Figure 3 -- *Typical radial growth curves for California black oak on two plots on the moist end of a precipitation gradient in the San Bernardino mountains.*

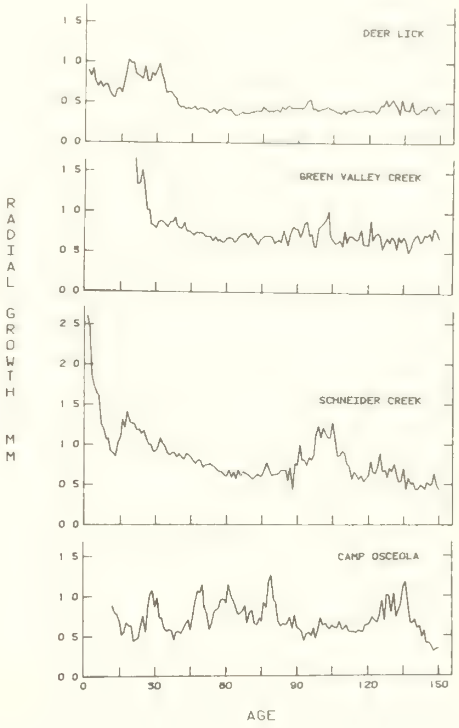


Figure 4 -- *Typical radial growth curves for California black oak on four plots on dry locations along a precipitation gradient in the San Bernardino mountains.*

that air pollution may have a significant impact on height growth of damaged oaks, since most of the height growth depends on carbohydrates produced and stored at the end of the summer. In contrast, the effect on radial growth of an oak exhibiting smog-damaged leaves might be hypothesized as one of a moderate growth diminution. Whereas conifers may be greatly weakened and susceptible to mortality after a series of poor growth years, oak species have the unique characteristic of being able to survive for extended periods at extremely small radial growth rates, and still respond quickly to improved conditions (Gingrich, 1971). At some point, however, sustained damage must reach a point that exceeds even the resilient capabilities of the oaks. Figure 5 graphs the actual radial growth curves from two trees of the same age from the Camp O-ongo plot, which experiences severe oxidant doses. Both trees withstood a period of drought in the late 1940's, prior to the presence of air pollution. Within the smog period from approximately 1950 to the present, one tree (#834) appears to have suffered little air pollution injury, while the other (#882) is in obvious decline. Leaf injury ratings obtained from 1974 to 1978 (see Miller's contribution, these proceedings) suggest that these trees are showing two extremes of responses to air pollution. At present, the internal and external factors responsible for the apparent differential response in radial growth is unknown. The remainder of the Tree Growth Project's work with black oak will be designed to identify and quantify these factors contributing to these two different responses. Additionally, the magnitude of each response throughout the San Bernardino mountains will be assessed.

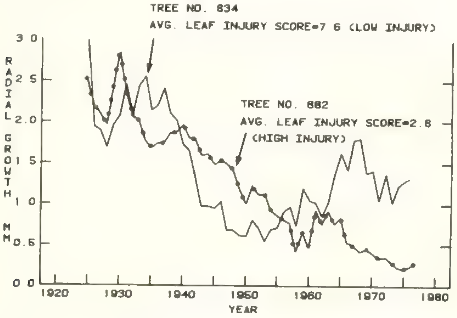


Figure 5--*Actual growth curves of two equal-aged black oaks on the Camp O-ongo plot.*

SUMMARY AND CONCLUSIONS

The following discussion pertains solely to black oak in specific locales in the San Bernardino mountains. There is no data to verify whether the San Bernardino population does or does not significantly differ from black oak populations elsewhere.

Two increment cores per tree may be adequate to describe radial growth of black oak only when old and leaning trees are excluded. Study trees should be selected for relatively straight growth habits, and caution should be exercised in deriving conclusions from year to year variation in very old trees.

Increasing number of stems per clump does not appear to dampen radial growth rates, although the nature of the competitive relationship between stems in a clump deserves more study, particularly in relation to site factors. Site factors and age are the strongest determinants of radial growth. The effect of age, or growth stage of the tree should be controlled for or removed before it is possible to compare radial growth rates between trees. The present analysis indicates that diameter cannot effectively replace age in predictive equations for radial growth, for obvious reasons. A tree may be small in diameter either because it is young, in which case it is in its most rapid period of growth, or because it is growing very slowly. Height and diameter should be modelled as the interrelated results of the trees' internal growth dynamics, with at least one important feedback being that radial growth correlates possitively to height.

The site index utilized here to summarize site factors is useful as an initial approximation to the importance of site. However, it merges together an assortment of diverse environmental features, such as the precipitation and temperature regime, stand density, and past history. The identification of site qualities contributing to growth differences needs considerably more analysis before radial growth can be described quantitatively.

California black oaks in the San Bernardino mountains experience a rapid flush of radial growth as young trees, reaching growth rates up to 3 mm per year within the first 25 years on the better sites. After 50 years of age, growth fluctuates closely around a much lower rate, also depending on site.

Although black oak may be expected to respond less severely to air pollution damage than coniferous species, damage is visible in the radial growth patterns of some individuals.

Assessment of this damage awaits the identification and quantification of external and internal factors, as mentioned above.

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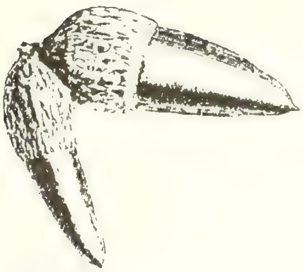

Quercus agrifolia

Prescribed Burning in California Oak Management[1]

Lisle R. Green[2]

Abstract: Prescribed burning is aimed at reducing hazardous chaparral and other fuel accumulations, beneath or near trees. Because most California oaks have thin bark and almost any fire causes serious damage to boles or crowns, some hand cutting, or clearing with a small bulldozer, may be necessary before burning. Prescribed burning can be accomplished safely in fuels not directly under or adjacent to canopies. Prescription items discussed are ratio of dead-to-live fuels, fuel volume, green and dry fuel moisture, relative humidity, windspeed and direction, and air temperature. Other considerations are terrain, time of day, and season of year.

INTRODUCTION

When we talk of prescribed burning in California oak management, we are usually concerned about burning chaparral with as little damage to oak trees as possible. We want to remove brush fuels or, occasionally, other fuel accumulations that could threaten stately old oak trees or thickets of trees during wildfires. Another reason for a prescribed burn is to reduce numbers of oak trees, as when burning for range improvement.

THE FUELS PROBLEM

Oak frequently dominates on northerly exposures, as stringers along low elevation riparian zones, or it may mix with conifers or other woodland species at upper elevations. Usually we find an understory of brush, or brush surrounding and fingering through the oak woodland. If the oak is dense enough to exclude brush, the tree canopies often extend to the ground. The fuel within the stand then consists of dead or nearly dead shrubs and dead and live branches and litter from the oak trees (figs. 1, 2).

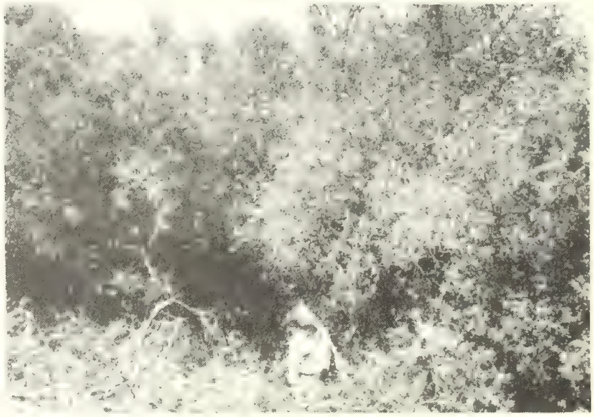

Figure 1--Thick oak stands require hand or mechanical thinning, or burns prescribed to remove only small amounts of fuel per burn, to prevent destruction of the trees.

The brush--or "chaparral"--is frequently dominated by chamise (Adenostoma fasciculatum H. & A.). Associated species and genera are manzanitas (Arctostaphylos spp.), ceanothus (Ceanothus spp.), mountain mahogany (Cercocarpus betuloides Nutt.), scrub oak (Quercus dumosa Nutt.), salvia (Salvia spp.), and others. These shrubs contain fats, waxes, terpenes, and oils that are readily extracted in the laboratory as "ether extract." These materials are also readily driven off when heat is applied during wild or prescribed fire and they burn violently 5, 10, or 50 feet (1.5, 3, or 15 m) in the air.

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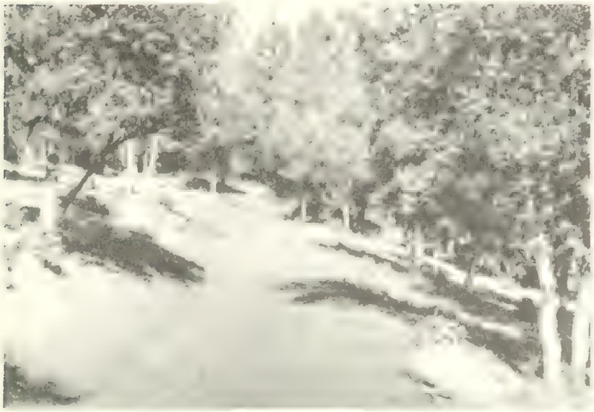

Figure 2--Hand labor was used to prune trees and pile underbrush, which was burned. Low intensity broadcast burning can now be used to control fuel accumulations.

The chaparral may contain little dead fuel in young stands, or from 35 to 50 percent in aged stands. Most of the dead material is distributed through the living shrub crowns. Brush in southern California generally has relatively little fuel on the ground, so fires travel through the brush crowns, and into tree canopies, if they are above or adjacent.

A herbaceous understory is usually lacking beneath dense chaparral, but a sparse stand of herbaceous plants, mostly annuals, is observed frequently where the brush stand is open. After fire or other clearing, seed from these plants and from seed stored in the soil, sometimes for decades, start to grow. Forbs--herbaceous, nongrassy plants--are abundant at first, but from 2 to 5 years after the initial clearing annual grasses and longer-lived forbs, such as deerweed (Lotus scoparious Ottley), become abundant. After 5 to 7 years, woody vegetation from sprouts and seedlings occupies the site again, and for the next 10 or 15 years the young, succulent closed stand of brush does not burn readily, except under the most adverse burning conditions. Gradually, however, dead twigs accumulate, some litter builds up, short-lived species die or dieback during drought, and the ratio of dead-to-live plant material increases, so that the stand becomes more and more flammable. Until the chaparral is about 20 years old, most fires are extinguished before they reach 10 acres in size. As the brush ages beyond 20 years, wildfires tend to get bigger (Philpot 1973, Rogers 1942). The really big fires occur when the chaparral is from 30 to 40 years old, or older.

During wildfire that sweeps across thousands of acres (ha) of wildland vegetation, air temperatures are usually in excess of 100° F (38° C), relative humidities below 5 percent are not uncommon, and sustained winds from 20 to 70 miles per hour (32 to 112 km/h) are usually blowing. In late summer, dead fuels may contain from 3 to 10 percent moisture, and fine, green fuels 50 to 65 percent--less than one-half their green fuel moisture contents of early spring. With these conditions, fire spreads rapidly through the fuels that are within a few feet of the ground. Where these fuels are beneath the oak trees, a convection column of hot air and swirling, burning volatiles distilled from the green fuels will, as a minimum, burn holes through the canopy above. If the fuels near the ground are continuous under the canopies, and if the burning conditions are extreme--low relative humidity and fuel moisture, high air temperature, and windspeed--the entire canopy may explode into flames and consume the small branches. Strong winds, coupled with undercanopy fuels, may move fire through the canopies.

During the Big Bear Fire on the San Bernardino National Forest in 1970, and in other fires where forests or woodlands were destroyed, the damage to oaks was principally where trees were underlain by brush. The oaks survived the Big Bear Fire where brush fuel loading was at low levels. The vulnerability of an individual tree to fire appeared less related to attributes, such as bark thickness, crown stratification, or chemical content of the foliage, than to the distribution of brush fuels around it (Minnich 1973). In the Eastern United States, killing of oaks by wildfire was two to four times greater in unburned forest than in prescribed burns conducted during the previous 10 years (Little and others 1948). Fires went out in forested areas burned by prescribed fire 1 year before the wildfire.

There have been some favorable and some unfavorable data collected following fire in oak stands. On the positive side, oaks sometimes seem to be somewhat more fire resistant than much of the chaparral. Scrub oak and shrub live oak (Quercus turbinella Greene) contain less of the volatiles, 3.7 and 6.2 percent respectively, than flammable chaparral, which contains from 7 to 20 percent volatiles (Rothermel 1976, Montgomery 1976). The oaks generally are somewhat higher in green fuel moisture than chamise, and contain a lower proportion of dead-to-live fuel (Green 1970, Minnich 1973). Because of these and, perhaps, other variables, the only group of sclerophyllous species that showed resistance to fire during the Big Bear conflagration of 1970 was the oak woodlands (Minnich 1973). In a prescribed burn in southern California, 85 percent of live chamise was consumed, 75 percent of live manzanita, but only 45 percent of mountain mahogany and scrub oak (Green 1970).

The "bad" news is that California oaks, with the exception of coast live oak (Quercus agrifolia Nee) (Plumb 1980) and, perhaps, Engelmann oak (Q. engelmanni Greene) (Snow 1980), are thin-barked and stems and canopies are sensitive to fire. Canyon live oak (Q. chrysolepis Liebm.), on the site of the 175,000 acre (70,820 ha) Marble-Cone Fire in Monterey County, was described as "so sensitive and flammable as to invite self-destruction" (Griffin 1978). A wildfire may have few or no beneficial effects on a black oak stand, but has many bad effects. It kills most small stems, and scorches the stems and roots of larger trees, even though the bark is relatively thick. Scorching causes fire scars, which result in deformities, leave openings to admit rot and diseases, and serve as points of ignition when fire next goes through the area (Edwards 1957). Interior live oak (Q. wislizenii A.DC.) has thin bark, and topkills readily when fuels burn around the base of the tree (Plumb 1979). In the Eastern United States, oaks and other hardwoods are so sensitive that fire is not recommended for use in their management but, rather, is directed toward hardwood control (Fender 1976).

HAZARD REDUCTION

Because fire in chaparral located near oaks is one of the greatest threats to the oaks (fig. 3), what can we do? Alternatives to wildfire removal of the brush include prescribed burning, mechanical clearing, herbicides, hand labor, or some combination of these methods.

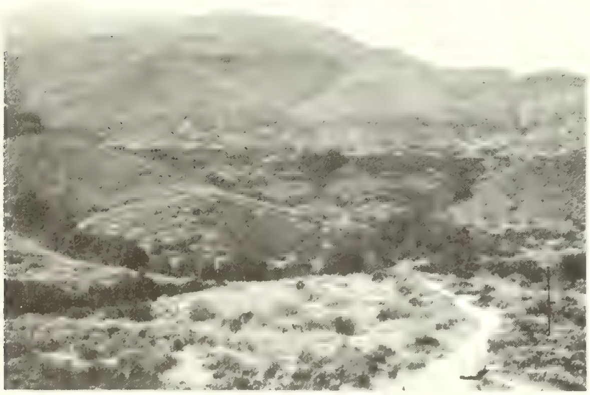

Figure 3--Security against wildfire can be attempted by crushing the brush adjacent to trees, and burning under a low intensity burn prescription.

Hand labor was used to clear brush during the late 1950's and 1960's when prison labor was available in quantity to agencies, and it is currently used to some extent when firefighting crews and other labor are not otherwise occupied. Hand labor is environmentally acceptable, but more expensive than other clearing methods. This high cost might be justified where the clearing is under or near valuable trees but, generally, would be prohibitive on any extensive scale.

Bulldozers can sometimes be used in and around oaks to push brush away from trees to be protected, or a bulldozer can crush brush for burning under relatively safe burning conditions. Use of the bulldozer can also be somewhat expensive because working around and under canopies, using care not to damage trees, is not conducive to high rates of production. If the bulldozer is needed to save oaks, however, it may be justified.

Herbicides may control or eliminate unwanted vegetation in some oak stands. They can be injected into tree trunks or applied to stumps of cut brush or trees. Aerial broadcast applications of herbicides is seldom appropriate because of potential damage to desirable trees, but tractor boom or hand spraying of brush sprouts within and around oak stands can be accomplished under appropriate wind, temperature, and humidity conditions. Use of herbicides after prescribed burning or hand clearing should be considered.

Prescribed burning will be needed to get rid of hand-cut brush piles, tractor-crushed brush, or standing chaparral. How is this to be accomplished?

Prescribed Burning

Prescribed burning of mature chaparral without damaging oaks presents problems that are difficult, or sometimes impossible, and we have rather little experience with this type of burning. Repeat burns should be easier. Personnel then have more experience with prescribed burning, deal with less fine flashy fuel, less total fuel, and fires are less likely to crown.

Numerous variables affect fire behavior, that is, the way it burns. It is convenient to discuss these variables individually, but they are all interrelated and, integrated by the fire, determine burning behavior.

Fuel Factors

Ratio of Dead-to-Live Fuels

Young chaparral stands--those less than 20 years old--will contain less than 20 percent dead material, and frequently only 5 or 10 percent. Such a brush stand is nearly fireproof, and will burn only under extreme burning conditions. Of the brush stands we work with in oak management, most are older--20 to 50 years of age. As brush ages, the proportion of dead fuel increases until aged stands may be from 35 to 50 percent dead. Such mature brush generally burns well under moderate burning conditions. If the brush has been crushed or treated with herbicide, or if snow breakage occurs, the proportion dead may be more than 50 percent.

Fuel Volume

Chaparral volume in California will vary from about 5 to 40 tons per acre (12 to 100 tons per ha), and average about 18 tons (44 tons per ha). During hot prescribed burn or wildfire, 65 to 80 percent of fine-stemmed, flammable brush, such as chamise and coastal sage species in a mature stand will burn; but only about 50 percent of less flammable species, such as mountain mahogany and scrub oak will burn. From theoretical studies (Byram 1959) and from experience we know that, as available fuel quantity increases beyond 2 to 3 tons per acre (5 to 7 tons per ha), the fire burns more and more intensely. For this reason, reburns with usually less flammable fuel, are generally easier to conduct safely than are initial burns. Ten tons per acre (25 tons per ha) of small flammable fuel--that which will burn during a fire--are considered heavy fuel accumulation (McArthur 1962, Norum 1977), and we have that much or more in most mature chaparral stands. This makes burning without damage to oaks difficult.

Fuel Moisture

Although the value varies somewhat depending on type of fuel, size of firebrand, windspeed, and other variables, a fuel moisture content of 25 percent of oven-dry weight is an approximation of the value above which fuels will not burn (Rothermel 1972). Fire spread is generally slow in small fuels containing more than 15 percent moisture, unless steep slope or strong winds boost the combustion rate (Britton and Wright 1971, Foster 1976, Heirman and Wright 1973, Rothermel and Anderson 1966, Sneeuwjagt 1974, and Forest Service n.d.). As fuel moisture goes up, or down, fire intensity changes proportionately (King 1973, Pace and Lindenmuth 1971, Rothermel and Anderson 1966, Forest Service 1968, and Forest Service n.d.).

Dead fuel moisture can be determined by laboratory procedures, but is usually estimated from special fuel sticks that represent dead fuels from 1/4 to 1 inch (0.6 to 2.5 cm) in diameter. Moisture readings of 6 to 12 percent, depending on the proportion of dead fuel, are needed for burning mature standing brush.

Green fuel moisture also influences fire behavior, although its effect may not be as obvious as that of dead fuels. Moisture content of the green fuel is always too high, above 25 percent, for the green twigs to sustain flaming without an outside heat source; but during summer and fall when moisture content of the twigs may be as low as from 55 to 65 percent, heat from flaming dead fuel dries the green twigs until they, too, burn violently. From experience and research we know that, if green fuel moisture is 90 percent or greater, burning these fuels is most difficult and much dead fuel is needed to sustain the flaming. For mature brush, a green fuel moisture no greater than 65 to 75 percent is generally needed for satisfactory prescribed burning.

Weather Factors

Relative Humidity

Humidity is the moisture in the atmosphere, and the relative humidity compares this moisture to the amount the air would hold if it were saturated, for example, 20 percent or 70 percent. Humidity affects moisture content of small dead fuels, which absorb moisture when the relative humidity is high, and release it when the relative humidity is low. The effect of humidity on fuels larger than an inch is small, except over long periods of time.

To burn standing brush near trees, we like relative humidity to be 25 to 40 percent. When the brush is crushed or cut and piled, from 30 to 60 percent relative humidity, depending on the dead-to-live ratio, is desirable.

Windspeed and Direction

Lack of ability to forecast local winds has been responsible for more prescribed burning escapes than any other variable affecting fire behavior. Weak storm fronts sometimes move in unexpectedly but, more frequently, erratic windspeed and direction because of local topography and convection aid escapes. Wind accelerates the oxygen supply to burning fuel, and contributes to heating of uphill or lee side of fuels. It carries away water vapor that dampens burning, and transfers firebrands beyond the fire front. Ten miles (16 km) per hour winds are usually considered the upper limit allowable for prescribed burning.

Although wind causes problems, it would be difficult to burn without some air movement. Without a flammable understory, such as dry grass, several miles per hour of wind--four to eight (6 to 12 km)--is needed to move fire through brush canopies. A little wind is needed to disperse heat when burning under tree canopies, and wind is needed to move fire through sparse fuels.

Air Temperature

Air temperature has less direct effect on fire behavior than humidity, fuel moisture, or wind, but affects these and other variables, and through them, fire behavior.

High air temperatures warm fuels so that less preheating by fire is needed before combustion occurs. Also, less heat energy is required to drive off moisture, and moisture evaporation proceeds more rapidly. Because of heating near the ground, high air temperatures can cause unstable air. This may result in strong convection currents and strong upslope daytime winds, which sometimes cause fire spotting and fire whirls. As temperature rises and relative humidity decreases, drying of fine fuels proceeds.

Some studies have suggested that prescribed burning be done when maximum air temperatures are less than 70° F (21° C), especially when burning under tree canopies (Biswell and Schultz 1956, Gaines and others 1958). A maximum of 80° F (26° C) was suggested for burning fuelbreaks (Schimke and Green 1970). Minimum temperatures can be as low as 30° F (-1° C), but low temperatures are usually accompanied by high relative humidities and high moisture contents of fine fuels. A temperature range of 60 to 70° F (15 to 21° C) would be nearly ideal for most prescribed burning. Brush piles or crushed brush can be burned under low temperature ranges.

Other Factors

Terrain

Slope has an effect on fire spread similar to windspeed: the steeper the slope, the more rapidly fire spreads uphill and the more slowly downhill. Prescribed fires usually are started near a ridgetop and allowed to back downhill, or to burn from the top of the hill in a series of narrow strips where the fire burns with the slope.

If the slope has a southerly exposure, fuels will be somewhat more flammable than on a northerly exposure. Frequently, it is easier to prescribe burn on south slopes because, when they will burn satisfactorily, northerly exposures generally will not burn, and this results in a natural fireline. If the exposure is northerly and ready for burning, the south exposures will burn intensely.

If local terrain is irregular, the problems of gusty, turbulent windflow and direction changes confront the prescribed-burn planner.

Time of Day

Conservative prescribed burning calls for reaching prescription and igniting during the hot part of the day, and burning into lowering air temperature and rising relative humidity. Fuels are as dry as they will be during this period, and as burning is extended into the late part of the day, control problems are less. For large burns, the objective might be to burn out a safe fireline and to burn under clusters of trees during the morning hours or the previous day, then allow fire through the rest of the burn when the air temperature is near maximum for the day.

Season

Where dead fuel accumulations are massive within a stand of trees, the objective should be to burn during late winter or early spring, or earlier during the winter if sufficient rain has fallen to wet 100-hour timelag [up to 3-inch (7.6-cm) diameter] or larger fuels, as well as litter. By burning when the larger fuels and deep litter will not burn, the flashy fuels--pine needles, fallen oak leaves, dry grass, and small twigs--can be removed with minimum damage to trees. If burning in such a stand is delayed until moisture content within the larger fuels is below 17 or 18 percent, they will add to the intensity and duration of the fire, and much more damage to tree boles and canopies will result.

CONCLUSIONS

California wildlands have been prescribe burned by permit since 1945, usually for range improvement. The objective frequently was to kill or severely damage stands of oaks. Only during the last year or two has burning to enhance the appearance and chances for survival of oak stands during wildfire been an objective. Experience in oak management burning, therefore, is limited, but is being expanded rapidly. Practices and principles learned in burning chaparral, ponderosa pine forests, and other fuel types are being modified to apply to prescribed burns in oak forests. Scientists in various disciplines are currently gathering knowledge about oak ecosystems, and this knowledge will aid in reducing the hazards of fire to California's oak stands.

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Nursery Propagation of California Oaks[1]

Suzanne Schettler[2/] and Michael N. Smith[3/]

ABSTRACT: California Oaks have been propagated by seed, cuttings, and grafting; but seed remains the most practical method. Initial planting of acorns in a bag or flat permits sorting and root-pruning before seedlings are planted into container or ground. Propagation and cultural practices vary with the purposes for which the oaks are produced.

INTRODUCTION

Propagation of California oaks by nursery methods is well suited to ornamental use. When it comes to forest and range plantings of oaks, the costs and benefits of these methods must be weighed for the particular application. On the one hand, direct broadcasting or dibbling into the ground may seem more economical if acorns are abundant enough after sorting to cover expected losses to foraging animals, drought, and other causes. On the other, a plant of gallon-can or equivalent size is a known entity that has already survived many initial hurdles; and early maintenance is less expensive in one nursery location than spread over acres of potentially rugged terrain. It may be promising, moreover, to borrow initial nursery techniques and then plant out at an early stage. The decision to use or not to use nursery methods at a given stage of seedling development will depend on the economic value of the trees and cost of alternative methods. Common principles apply to propagation for all purposes.

GOALS

Forestry

For timber use, a forester seeks oaks with consistently erect, straight boles, rapid rate of growth, and more or less even size. Clonal material may even be desirable. The strain must be well adapted to the local soil and climate. The trees must be of adequate size during the best planting season (mid-fall through mid-winter in mild climates, early fall in snow country), and must be able to establish themselves quickly and grow vigorously to harvest size.

Wildlife Management

A wildlife manager presumably seeks the full diversity of local ecotypes, and trees of varied growth habit are not undesirable. Mature trees should bear abundant acorn crops to provide food for wildlife. The wildlife manager shares with the forester an interest in locally adapted trees and in matching optimum planting size to optimum planting date. For large-scale forest plantings, there is a growing awareness that local genetic material should be kept intact: propagation should be from local trees only. This also applies to other large plantings such as along highways and in large housing subdivisions.

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Ornamental Horticulture

The typical ornamental nurseryman seeks predominantly aesthetic characteristics in a young oak, combined with potential for success in varied landscapes. The tree should resist disease and be adaptable to a wide range of climates and soil types. A given tree may be planted in a location hundreds of miles from its parent, on native soil, subsoil or fill, with drought or summer watering. It must be able to thrive in an artificial setting as well as in a natural one. Each tree should grow vigorously, become established readily in the ground, and not vary too much in form from the "classic" image of the species.

Thus, the goals of oak growers may vary. But they all share an interest in plants with a vigorous start, in the strongest possible state at planting time, and produced by the most economical method.

VEGETATIVE PROPAGATION

Propagation by seed has been the only method commercially successful thus far, and will be discussed in the next section. The considerable diversity inherent in this method can be partly limited, where desired, by selection of source trees, preferably within relatively uniform populations. The following are some methods of clonal propagation, applicable where the traits of specific selected trees are to be perpetuated.

Cuttings

Some propagation of oaks has been done from cuttings. However, most oak species are inherently difficult to root. Researchers to date have rooted only a few species, using elaborate equipment and such exotic materials as 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid]. And the numbers propagated by this technique have been too small to hold much promise for economical production on a commercial scale. However, it should be noted that many plant species thought to be difficult or impossible to propagate by this method in years past are now routinely and economically reproduced in this manner. Often the "breakthrough" has involved simple environmental, mechanical (as in hedging) or chemical manipulation of parent stock.

Grafting

Grafting has been quite successful with some European and eastern American species. It could prove worthwhile in certain applications, but has not been tried extensively for California species. The type of graft is dictated more by the preference of the propagator than by the plant; one of us has had very limited success with a simple side graft performed in January on coast live oak (*Quercus agrifolia*). However, grafting is a relatively expensive technique, requiring a strong motive for perpetuating an individual clone (as is frequently the case for ornamental use).

Tissue Culture

Tissue culture has produced only limited success with many woody plants, often resulting in proliferation and development of vegetative shoots without similar development of roots. We do not know of any sustained success with California oaks. Tissue culture is also fairly expensive on a per-unit basis, especially with slower-growing plants; but there is potential for nearly unlimited numbers of "identical" trees if this method were perfected.

ACORN PROPAGATION

The remarks that follow, unless otherwise credited, are based entirely upon our first-hand experience as commercial growers of oaks in central and northern California.

Collection

Collecting acorns presents as large a challenge as any later stage of propagation. Timing is crucial. The first wave of acorns to drop from a tree consists primarily of aborted and weevil-eaten acorns. Then, the good acorns drop a few days or weeks later. Not all trees bear equally heavy acorn crops. A given tree is not always consistent in its crop from year to year. And in some years, perhaps in response to aberrant weather during the previous season, a species may bear a poor or negligible crop throughout its range, as *Q. lobata* did in 1978 in much of northern California.

To physically collect acorns on the tree is slow and precarious, but gives the best percentage of sound acorns if they are gathered between the first and second drops and just as they loosen sufficiently from the cap to permit removal without damage. Gathering acorns from the ground is far easier and faster, as they sometimes can be raked or swept up. But this method also has its drawbacks. Unless the first drop has been raked or otherwise removed, the eaten and aborted acorns will be collected together with the good ones. And animals may beat the propagator in gathering *their* acorns.

In addition, acorns of different species may be mixed on the ground unless the parent tree is well isolated or growing in a pure stand. For large producers, it would seem advisable to maintain certain seed trees in the wild by spraying as needed against principal insect pests like the Oak Moth or California Oakworm (Phryganidia californica) and the Filbert or Acorn Weevil (Curculio uniformis), and by one or two deep waterings at the drip line during summers of extreme drought.

Sorting

Two kinds of sorting are required. Broken and crushed acorns and those with weevil holes in the shell must be visually sorted. And acorns that look good are generally floated as a rough test for viability--those that float are reliably bad, although those that sink are not always viable.

Storage

It may be necessary to store acorns if 1 full year's growth would produce a plant too big for planting the following fall. Acorns can be dried and stored at cool or cold temperatures, but in our experience, drying has reduced viability to an unacceptable level, particularly with Q. agrifolia. It might be possible to delay sowing, if needed, through lower-temperature moist stratification or even freezing; we have not explored these possibilities.

Stratification

Cold stratification (in which seeds are layered or mixed with a moist medium such as peat in a container and refrigerated) is sometimes used to break dormancy of the embryo, to permeate the seed coat without rotting the seed, and/or to even out the commencement of germination. However, with the possible exception of high-elevation material, the need for stratification in California oaks is questionable--a batch of fresh acorns often includes quite a few that have begun to sprout on the ground or surprisingly even on the tree. Even Q. kelloggii, a red oak species reported in the literature to require stratification, has germinated well and rapidly for us without such treatment. Chemical pretreatment with gibberellin or other chemicals might be tried, but likewise seems unnecessary for California oaks. In our experience, every low-elevation California oak species has shown good germination with no pretreatment other than careful sorting.

Sowing

Two problems quickly develop after sowing. Oak roots grow rapidly while the tops grow slowly. The nurseryman, though perhaps not the forester or wildlife manager, may seek to alter the root-shoot ratio to prevent early root binding in containers. (All three growers may be deceived as to root growth by observing only the tops.) And every batch of acorns will exhibit mixed viability and vigor, producing a need to sort and cull at the earliest, most economical stage.

Seed Beds

One traditional method of sowing is to plant in seed beds. This allows for unrestrained growth of strong roots, but unless they are frequently undercut to prepare them in advance, at lifting there is potential for mortal damage to the roots, at least in the case of evergreen species like Q. agrifolia. Deciduous species can regenerate roots after heavy cutting if lifted while they are leafless and dormant. The seed bed method permits the use of inexpensive space and ease of irrigation and fertilization. With proper timing, seedlings can be transferred directly from the seed bed to a permanent planting site.

Seed Flats

Planting in seed flats is very space-economical, although it is a two-step method. It permits easy handling and the sorting so essential at the earliest stage of seedling development. Growth rate can be manipulated inexpensively by moving a flat to a warmer or cooler environment. In our central coast climate, outdoors is cooler than on the greenhouse floor, which, in turn, is cooler than on a greenhouse bench. Growth rate can also be manipulated by raising or lowering nutrient levels. But, unless seedlings are transferred to individual containers soon after germination, roots become crowded and hopelessly tangled in the flat. With refinements, we believe this could be one of the best methods for propagating oak plants. Deep flats that hold 3-1/2 inches (9 cm) or more of sowing medium are needed to provide uncramped root space. And a copper screen or treated bottom on the flats causes air and/or chemical pruning of the tap root which induces root-branching.

Pots

Acorns are sometimes planted directly into individual pots, a method used extensively to grow coniferous species for timber use. The advantage of this method, if pots are deep enough and seed is of known high quality, is that it is theoretically a one-step process. However, the pots most commonly used in nurseries are too shallow for oaks and acorn viability may be unknown. The less vigorous individuals cannot be culled before a considerable investment in materials has been made, and it is difficult in a pot to "correct" a root system. The best container for this purpose is one 2 to 4 inches (5 to 10 cm) square by at least 7 to 8 inches (18 to 20 cm) deep, either a bottomless band or a fiber pot whose bottom decomposes after a few months. However, availability of pots this size is limited. They are also heavy and awkward to handle in standard shallow flats.

Plastic Bags

The most successful method of starting acorns that we know was passed on to us by W. Richard Hildreth while Director of Saratoga Horticultural Foundation. Sorted acorns are mixed with damp sand, vermiculite, peat, or sphagnum in a plastic bag and kept between about 50 and 75° F (10 to 24° C). This is not the classic "cold stratification," which it superficially resembles, but a method of sowing. The acorns begin to sprout in the bag within a few months or even weeks. They will continue to germinate over an extended period, but in practice, the slow sprouters tend to remain less vigorous at all later stages and are best discarded. (This, of course, means many more acorns have to be collected than the anticipated crop.) When the root is 2 to 3 inches (5 to 8 cm) long, it is tip-pinched to induce branching (particularly desirable if the plant is to be container-grown) and planted directly into a moderately large container such as the one described above or a gallon can. At this stage, shoot growth may still not have begun. The seedling may be sown with acorn on the surface of the soil, or may be placed an inch or so below the surface.

The only disadvantages of this method occur when the seedlings are left in the bag too long: the shoot will grow bent after it reaches the light at the surface of the bag, the roots will become tangled, and the whole mixture can rot. But, properly timed and maintained, this technique is well adapted to the need to keep pace with rapidly-developing vigorous roots, to sort at the earliest opportunity, and to prune and straighten roots at the most formative stage. It requires little environmental control and no pre-transplant feeding or watering. It is economical of space, as bags can be kept in unused space under greenhouse benches. And it could provide the most effective shortcut for forest planting in mild climates: acorns, collected as they drop, could germinate in bags quickly enough to plant directly into the ground within a matter of weeks. Where losses are high from feeding by jays and other acorn-eaters, once a root and top are producing food for the seedling, the acorn which is their main attraction can be clipped off.[4/]

Transplanting

Transplanting from either a bag or a flat provides a prime opportunity to cull undesirable plants and to tend roots of select individuals. At this time, lateral roots regenerate freely after the tap-root is cut, whereas to cut heavy roots at later stages tends to produce shock and setback. The kind of root system ultimately desired can be partly determined by how hard and how frequently the roots are pruned while the seedlings are still young. Here the ornamental nurseryman will likely diverge from his forest or wildlife counterpart, deliberately forcing development of a branched root system ideal for planting into successively larger containers.

Container

Selection of container may be a compromise of factors. For the forester or wildlife manager, a deep root system that helps the plant become established quickly in the ground must be weighed against problems of digging a deep planting hole and the logistics of moving heavy containers. Here, also, container cost is critical, with cheaper materials such as polyethylene film, cardboard, or tarpaper often being preferred. For a nurseryman, container cost is less restricting. As mentioned before, for any grower, it is possible (and desirable) to transplant directly from the bag or flat to a 1-gallon can or its depth equivalent.

Medium

Nearly any reasonable planting medium can be used with good results as long as it is well-drained. Planting mixes usually employed in the ornamental nursery include various mixtures of conifer sawdust or shavings (most frequently Redwood [Sequoia] or Douglas-fir [Pseudotsuga]) and any of a wide variety of sands, soils, or volcanic materials. Soil of any sort should normally be sterilized, while

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[4/] Personal communication with Wayne Poderick, Director, Botanic Garden, Tilden Park, Berkeley, California.

the other materials tend to be acceptably low in pathogenic fungi and other organisms. If the young plants will be outplanted into dense high-clay soils, it is advisable to use a relatively dense nursery mix, with watering and other nursery care adjusted accordingly. Some clay content is highly desirable in any case for retention of nutrients.

After this first potting, it is important to minimize posttransplant shock. The seedlings should initially be kept in a cool location with an even supply of moisture, and given half shade, particularly if moved during the longer, hotter days of spring or summer.

Culture

Culture of oak seedlings for ornamental use is geared toward achieving maximum growth at all stages. This is accomplished by giving the seedlings constant optimum conditions and avoiding stress. The soil mix should always be moist (permitted by a porous, well-drained mix). The presence or absence of nutrients seems to make little difference in growth until seedlings are 2 or 3 inches (5 or 8 cm) high. At later stages, most oak species are as responsive to high fertility as most other woody plants; differences produced in growth rates of Q. agrifolia, Q. wislizenii, and Q. lobata can be spectacular. Temperatures should be moderate; in theory a winter-heated house could permit year-round growth. Summer shade permits more vigorous growth during the first year or two. And although probably not economical, long-day lighting should accelerate growth.

Root-Pruning

Root trimming may be necessary at each successive move to a larger container in order to keep roots from growing cramped or coiled while the top reaches saleable size. It is critical to keep roots growing actively and freely. As alternatives to screened containers or bottom-treated flats to prune and induce early branching of newly-germinated roots, open-bottomed containers or plant bands produce the same effect at the transplanting stage; as the pots are moved from one location to another the roots are pruned in the process. Fiber pots tend to rot away at the bottom and become open-bottomed containers with time. It is most desirable to transfer young plants rapidly to the next larger container or to the ground, as soon as roots have filled the current container.

Staking

Staking is generally not necessary. A grower may wish a tree for timber or ornament to have a strongly upright lower trunk. However, staked trunks tend to be weaker and to develop less rapidly in girth than unstaked trunks. Both single-trunked and multitrunked trees are desirable for landscape use, and a gnarled trunk can increase an oak's aesthetic value. If taller trees are desired, judicious pruning of weaker secondary trunks may be more useful than staking.

Pests and Diseases

Young oaks in the nursery are as subject to pests and diseases as are other plants, and early detection is important because treatment is most effective when these problems first appear.

Aphids frequently occur in closely packed nursery blocks, particularly of Q. agrifolia and Q. kelloggii during April and mid-September through mid-October. They can seriously distort growth, but seldom kill the plants. Whiteflies occur occasionally in summer, again where blocks of plants are overpacked so that much of the foliage is shaded. Both aphids and whiteflies are treated effectively with such systemics as Orthene (safest to the user), Cygon or Metasystox which give extended control. One application generally lasts 1 to 3 months. Quick knock-down without lasting control can be obtained with Diazinon, Malathion, Sevin, or other short-residual surface insecticides.

Oak Moth Caterpillars are not usually a nursery problem. They, and similar species, can skeletonize young foliage but, again, are usually not lethal. Control is obtained with such materials as Orthene, or with Lindane which is not systemic but leaves a long-term crystalline residue effective where eggs hatch over a period of weeks. Dipel and other formulations of Bacillus thuringiensis give effective biological control. Broad-spectrum, short-term, insecticides give control if all the caterpillars have hatched at the time of application.

Stem gall insects such as the Woody Twig Gall (Callirhytis perdens) can do very serious damage, especially on Q. agrifolia and Q. wislizenii, where they girdle twigs and virtually ruin many young trees. Chemical control is extremely difficult; probably the most effective measure would be to enclose plant blocks with shade or other cloth of sufficiently fine mesh to prevent entry by the adult insects.

Powdery mildew may be a problem in late summer, primarily in sprinkler-irrigated nurseries and in foggy coastal locations. It can seriously distort new growth and cause "witches' brooms." Many chemicals are available specifically for it, although there may be registration problems for use in oaks; Dithane, Karathane, Kelthane, and Pipron are registered for powdery mildew. Benlate is often effective only at increasingly high concentrations. Repeated sprays of Captan, alone or in combination with other fungicides, can give effective control. Benlate and Captan also control Botrytis, which can be a problem under cool, wet conditions particularly in early spring.

Fungus twig blights and root rots are often caused (especially in sprinkler-irrigated nurseries) by Pythium and Phytophthora. Truban is probably the best currently registered control, while Captan is a reliable standby.

All these diseases are prevented by generous plant spacing, and hand- or other short-duration or non-overhead watering.

Under continuous good culture, it is not unusual here for the low-elevation deciduous oaks (Q. kelloggii, Q. douglasii, Q. lobata) to attain 1-1/2 to 2 feet (46 to 61 cm) of top growth by the end of the first summer in the nursery. Q. agrifolia may reach 2 to 3 feet (61 to 91 cm). At the end of the second year, the deciduous species will have grown to 3 to 5 feet (91 to 152 cm) in 5-gallon cans and coast live oak to 5 to 8 feet (152 to 244 cm).

Outplanting

When it is time for final planting into the ground, several factors must be taken into account. Is water available for a few deep irrigations during the first dry season? If not, the young plant must be planted with, or just ahead of the first rains. Planting should be timed and tended so that extremes of temperature, wind, and drought are prevented. Under ideal conditions, a vigorous oak seedling can be planted out and experience little or no interruption in its growth. However, if the timing and situation of planting will be less than ideal, the plant should be hardened off well in advance to prepare for the new environment. Nutrients can be gradually reduced, periods between watering gradually lengthened, and exposure to hot sun increased so that a tougher plant goes out to compete in the wild, less dependent on human care.

The propagator's success shows up not in the nursery, but many years later when wildlife or humans, with no thought of propagation, enjoy a healthy stand of oaks.

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Quercus dumosa

Nutrient-Microbial Considerations in Oak Management[1]

Paul H. Dunn[2]

Abstract: Nutrient data for California Quercus woodlands has been extracted and is presented in table and graph form to facilitate comparison of individual sites with other sites. Nutrient cycles, with emphasis on carbon, nitrogen, and phosphorus, are reviewed for Quercus. Fertilizer use in Quercus woodlands is reviewed. Nonsymbiotic dinitrogen fixation and mycorrhizal associations with Quercus are discussed and four mycorrhizal fungi species producing hypogenous fruiting bodies in association with Q. dumosa are identified.

INTRODUCTION

Recognizing the value of oak woodlands for recreation, wildlife, and wood production is the impetus behind current oak outplanting programs. A major influence on the success of such oak productivity is the nutrient-microbial condition of the soil.

Microbial activity in soils is generally little understood but critical to the success of many management plans, particularly those involving outplanting, introduction of oaks, and increasing productivity of oak-dominated sites. For this reason, microbial conditions and the interrelationship to nutrient pools must be taken into account.

This paper is designed principally to give oak woodland managers a reference to compare the nutrient status of their sites to nutrient levels in other oak woodlands and thereby predict results of proposed management activities. Much of this information, which is sparse and scattered throughout the scientific literature, is summarized here with emphasis on California oak woodlands, though other areas are considered as well.

NUTRIENT BUDGETS IN OAK WOODLANDS

Oaks rarely occur in pure stands. Most of the data presented here are therefore derived from woodlands in which oak is the dominant overstory species, but not the exclusive species on the site. The information has been gleaned from many different scientific papers so the nutrient budget is not complete for every site; however, the budgets presented hopefully will indicate a range of values against which a site can be judged before management activities are proposed and some prediction of success can be made.

Much of the California oak data is extracted from the California Soil Vegetation Survey which, though not complete for all areas of the State, provides some usable budget values. These data include unpublished resources and were made available by Paul Zinke[3] of the University of California, Berkeley. The criterion used by the author to classify a site as oak woodland--based on California Soil Vegetation Survey data--was an excess of 50 percent cover of oak or an oak-grass savannah.

Quantities of nutrients in various pools do not alone give complete information about the nutrient conditions of a site. The rate of transfer between pools is also important. A site with high turnover rates between pools can be as productive as that site with large nutrient pools but with slower recycling rates.

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The Carbon Cycle

Gross primary production, or energy, is fixed in carbon compounds during photosynthesis. Oaks metabolize part of the gross primary production as respiration; the remainder generates biomass, or net primary production. Each fall, deciduous oaks drop most of their net primary production in the form of leaves onto the litter layer. Conversely, evergreen oaks keep their leaves 1-1/2 to 3 years, which means that less of their annual energy production is expended in regenerating leaves. The evergreen oaks do tend to drop their oldest leaves primarily during the fall, but it is not a complete drop (Wheeler 1975) as in deciduous species.

Prior to falling, leaves of many tree species are infected by initial decomposition fungi (Jensen 1974). When the leaves are deposited on the upper layers of litter, they are invaded from below by soil fauna (Dickinson and Pugh 1974) which chew the leaves into even smaller pieces. Much of the leaf material is left partly decomposed in fecal pellets. Successive waves of microbes then decompose leaves and fecal pellets with extracellular enzymes.

Readily decomposed carbon-containing compounds, such as sugar, are metabolized first, mostly by sugar fungi such as Zygomycetes (Jensen 1974). Next, cellulolytic microbes slowly decompose the cellulose. The resistant lignins which remain are then very slowly decomposed. The final links in the decomposition chain are the humic compounds which, because of very long half-lives in the soil, take 100 to 1000 years to decompose. These humic compounds may originate directly from the litter or from microbes involved in decomposition. Each step in the decomposition process involves a different microhabitat and a different complement of microbes. Near the bottom of the litter layers only lignin and humic compounds remain. This layer, which becomes anaerobic when wet, is referred to as the fermentation layer.

The decomposition time of a leaf in litter varies in proportion to resistant compounds in the leaf and the environmental conditions. For example, Edwards and Heath (1975) found that increases in the polyphenol content of Q. robur L. leaves decreased the decomposition rate. Yielding (1978) showed that in San Diego County chaparral, Quercus dumosa foliage decomposed 21.12 percent in 18 months. In the same time and place, Ceanothus greggii foliage decomposed 12.8 percent, Adenostoma fasciculatum decomposed 15.05 percent, A. sparsifolium decomposed 20.18 percent, Arctostaphylos glandulosa decomposed 18.81 percent, and Cercocarpus betuloides decomposed 23.07 percent.

In oaks, decomposition takes place through a combination of micro-organisms and soil invertebrates. But within a narrowly defined system, some inherent differences in decomposition rates occur by species and site. For example, the decomposition rate in temperate oak woodlands is higher than the decomposition rate in San Diego chaparral sites recorded by Yielding, partly due to the dry climate of the chaparral which limits the amount of time conditions are suitable for decomposition (Winn 1977, Olson 1963, Yielding 1978). In England, foliage of Quercus robur L. decomposed 40 percent in 18 months (Edwards and Heath 1975). An oak-hickory forest in southern Illinois was estimated to decompose one-half of the litter in 10.5 to 17 months (Akhtar and others 1976). Litter from a mixed oak forest in New Jersey had 65 percent decomposition in 18 months (Lang 1974). An oak-pine forest litter on Long Island lost 66 percent of its weight over 1 year (Woodwell and Marples 1968). In 6 months, Q. alba underwent 28 percent decomposition and Q. velutina had 29 percent decomposition (Broadfoot and Pierre 1939). In the same 6-month period, Q. petraea lost 26.20 percent in English mull, 23 percent in moder, and 22 percent in peat. Q. robur lost 17 percent each on three separate sites in 6 months (Bocock and Gilbert 1957).

As a juvenile oak woodland ages, the depth of the litter layer changes. In juvenile stages, the depth of the litter layer gradually increases. In a mature temperate zone oak forest, a nearly steady state is achieved, with litter deposition equaling litter decomposition (Lang 1974). Such may not be true for stands where nutrients become limiting or where the amount of resistant compounds in leaves increase. The result is a longer decomposition time (Edwards and Heath 1975), offset only partly by better moisture retention in the thicker litter layers. The dense, closed canopy of older stands also decreases the temperature in the litter layer, thereby slowing decomposition. In some areas, environmental conditions are such that equilibrium is never achieved, mostly due to dryness (Olson 1963). For example, the California oak savannah does not develop deep litter layers, perhaps due to the high water-holding capacity of the soil and high levels of rodent and arthropod activity which breaks up litter and moves it down into soil where decomposition is rapid.

Microbial respiration accounts for 99 percent of the CO_2 produced from the litter and soil (Ausmus and Witkamp 1974). The actual proportion of respiration attributable to bacteria, fungi, roots, and other soil organisms is not easily ascertained. Of the microbe-produced CO_2, about 78 percent is due to fungi, about 22 percent is due to bacteria (Anderson and Domsch 1973). These percentages may attribute too much activity to bacteria in oak woodlands, since the acidic litter in the oak woodland ecosystem selects in favor of acid-loving fungi.

Most microbes are dependent on photosynthetically fixed carbon as an energy source. The distribution of carbon, therefore, closely parallels the distribution of microbes, as demonstrated by selected California oak stands (fig. 1). Although no microbial data was developed for this study, microbial activity should parallel the carbon biomass in the upper soil layers. This may not be true for the carbon increase seen below 50 cm.

Zinke[3/] has developed Weibull distributions for the carbon content of soil to 5 cm stands of Quercus dumosa throughout the State (fig. 2). Using this curve for comparison, the relative richness of any given site to other sites in the State can be made. Any site which falls on the low end of this distribution should be considered marginal.

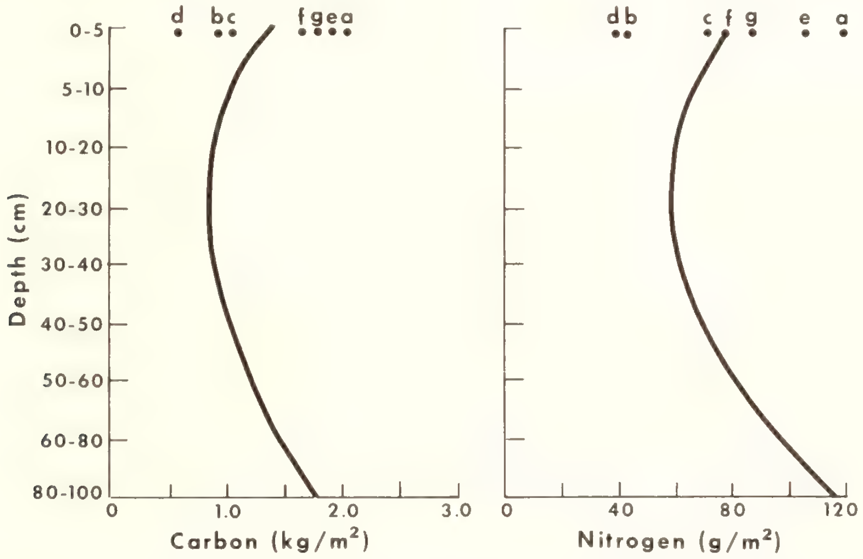

Figure 1--Carbon (kg/m^2) and nitrogen (g/m^2) soil profiles from Quercus dumosa sites in southern California: (a) Kiethly Ranch, Lake County, Calif., (b) Owl Canyon, Hollywood, Calif., (c) El Prieto Canyon, Los Angeles County, Calif., (d) Scissors Junction, San Diego County, Calif., (e) Sunrise, San Diego County, Calif., (f) Descanso (4 mi NE), San Diego County, Calif., and (g) Vista (5 mi S) San Diego County, Calif. (Data supplied by Paul Zinke, University of California, Berkeley).

For example, quantities for chaparral sites (fig. 1) generally fit in the mid-to-lower range.

The Nitrogen Cycle

Nitrogen--essential to all living organisms--is a component of the amino acids which make up protein. Nitrogen gas is the principal component of air (≈ 80 percent), however, it is not in a form usable by most organisms. Through symbiotic association with a microbe, some plants are able to fix nitrogen from the air into a usable form. The legumes and members of the genus Ceanothus are typical. Dominant chaparral shrubs reflect this nitrogen-fixing ability (fig. 3) in their foliage nitrogen content. Ceanothus cannot exist on sites which do not provide sufficient nitrogen from soil or allow fixation to maintain leaf tissue concentrations greater than 1 percent. Quercus dumosa, which does not fix its own nitrogen, reflects the available nitrogen of a site in its foliage. Plants can maintain the same foliage nitrogen level within a broad range of soil nitrogen levels. Changes in foliar nitrogen levels occur at the extremes of soil nitrogen concentrations. Soil nitrogen is the most direct measure of the nitrogen condition on a site. The Weibull distribution of *Q. dumosa* soil nitrogen content (fig. 4) provides a measure against which a site can be compared (fig. 1).

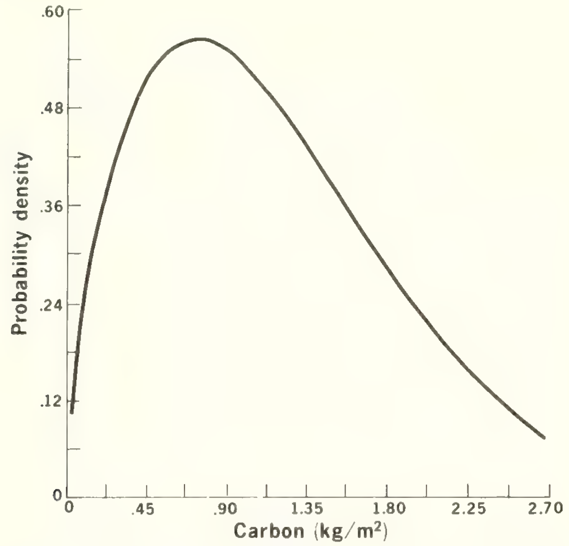

Figure 2--Weibull function for carbon for California *Quercus dumosa* soil (0-5 cm) (Data supplied by Paul Zinke, University of California, Berkeley).

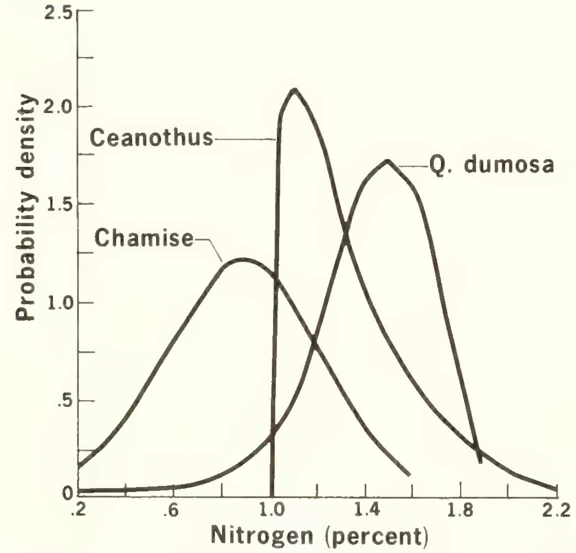

Figure 3--Weibull function for California chaparral foliar nitrogen (Data supplied by Paul Zinke, University of California, Berkeley).

Another method of assessing site quality is the carbon-nitrogen ratio (C:N) of leaf litter and soil on a site. Sites rich in nitrogen have a low carbon-nitrogen ratio. In sites low in available nitrogen, the ratio increases. Profiles for several oak woodland sites in southern California illustrate the range of carbon-nitrogen ratios occurring in the top meter of soil (table 1). The *Q. douglasii* sites (oak savannahs) generally have lower carbon-nitrogen ratios than other California oak species.

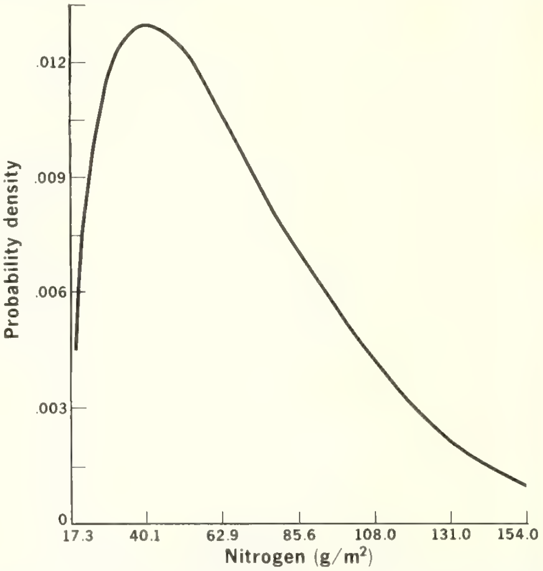

Figure 4--Weibull function for nitrogen for California *Quercus dumosa* soil (0-5 cm) (Data supplied by Paul Zinke, University of California, Berkeley).

Leaves are an important part of the nitrogen budget in an oak woodland. Depending on size, leaves were found to constitute 3 to 7 percent of the total tree biomass aboveground in the Georgia study performed by Monk and others (1970). Leaves in California are commonly 1 to 2 percent nitrogen (Wheeler 1975). Post oak-blackjack oak forests in Oklahoma have a nitrogen content of 2.4 percent in post oak and 3.4 percent in blackjack oak (Johnson and Risser 1974). The quantity of leaf nitrogen is related to nitrogen availability within the woodland. Leaves normally acquire all of their nitrogen early in their growth (Sampson and Samisch 1935). Before oaks drop their leaves (every year for deciduous species, every 1 to 3 years for evergreen species), much of the nitrogen in the leaf is translocated from the leaves to the woody tissue. The percentage retained by the tree varies from 72 to 77 percent for California oaks (Wheeler 1975). *Q. dumosa* is an exception, with 27 percent retention (Sampson and Samisch 1935, Wheeler 1975). Much of the nitrogen left is in structural materials resistant to microbial decomposition.

Decomposition of nitrogenous compounds in leaf litter is similar to the decomposition of carbon compounds. The nitrogen is made soluble by extracellular enzymes from microbes. From there, the nitrogen may be leached into the

Table 1--California Soil-Vegetation Survey data for the top 1 meter of soil in oak woodlands.

Plant	Cover	Carbon	Nitrogen	Phosphorus[1]	Carbon-nitrogen ratio	Soil	County	Quad/Plot	PPTN	Elevation
	percent	kg/m^2	g/m^2	mg/m^2	C:N				mm	m
Quercus douglasii	20-50	3.06	317.47	23	9.6	Trimmer	Fresno	100B1/11	381-482	460
Grasses	80-100									
Q. douglasii	5-20	10.97	871.82	4122(B)	12.6	Supan	Tuolumne	79A1/07	635-737	340
Pinus sabiniana	<5									
Grasses	50-80									
Q. douglasii	20-50	6.52	698.34	578(B)	9.3	Wisheylu	Calaveras	68D2/02	635-737	640
Grasses	50-80									
Q. douglasii	20-50	8.59	772.84	106	11.1	Sacata	Fresno	100A2/11	762-864	1040
Grasses	80-100									
Q. douglasii	20-50	6.28	726.56	1759(B)	8.6	Whiterock	Calaveras	68D3/01	635-737	370
Grasses	80-100									
Q. douglasii	20-50	5.34	1095.49	3991(B)	4.9	Whiterock	Calaveras	79A2/04	635-737	270
Grasses	50-80									
Q. douglasii	20-50	6.31	659.73	433	9.6	Laniger	Tehama	41A1/01	508-610	60
Grasses	5-20									
Q. douglasii	20-50	5.76	687.75	617(B)	8.4	Argonaut	Butte	50B3/01	635-737	60
Grasses	80-100									
Q. douglasii	20-50	7.20	318.82	101(B)	22.6	Argonaut	Yuba	50A3/04	1143-1245	520
Grasses	20-50									
Ceanothus	5-20									
Q. douglasii	20-50	3.03	341.77	353(B)	8.9	Amrogosa	Butte	50B3/04	762-864	240
Grasses	50-80									
Q. douglasii	20-50	5.84	429.70	439(B)	13.6	Auburn	Butte	39C3/08	889-991	300
Grasses	50-80									
P. sabiniana	5-20									
Q. douglasii	5-20	3.72	485.66	346(B)	7.7	Auburn	Calaveras	79A3/01	381-482	240
Grasses	80-100									
Q. douglasii	20-50	6.00	564.01	1722(B)	10.6	Exchequer	Calaveras	79A1/01	508-610	300
Grasses	80-100									
Q. douglasii	20-50	3.84	444.74	824(B)	8.6	Exchequer	Calaveras	79A2/02	508-610	200
Grasses	80-100									
Q. douglasii	20-50	8.55	686.37	0	12.5	Auberry	Butte	39C3/10	1143-1245	490
Q. douglasii	20-50	6.90	450.33	20		Guenoc	Shasta	32A1/10	762-864	280
Grasses	50-80									
Q. douglasii	20-50	5.86	517.32	161(B)	11.3	Sobrante	Calaveras	79A2/05	508-610	240
Grasses	50-80									
Q. lobata	<5	14.08	794.53	2867(B)	17.7	Chualar	Yuba	50B4/04	1106-1118	430

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[1] (B)=data for bicarbonate extraction; otherwise water extraction

Table 1—Continued

Plant	Cover	Carbon	Nitrogen	Phosphorus[1/]	Carbon-nitrogen ratio	Soil	County	Quad/Plot	PPTN	Elevation
	percent	kg/m^2	g/m^2	mg/m^2	C:N				mm	m
Q. wislizenii	<5									
Grasses	80-100									
Q. wislizenii	20-50	8.01	336.17	535(B)	23.8	Sobrante	Yuba	50B4/01	762-864	340
Q. wislizenii	80-100	0	0	12	0	Shaver	Fresno	90D2/01	889-991	2190
Q. wislizenii	80-100	7.60	566.88	35	13.4	Ahwahnee	Fresno	90C4/09	635-737	730
Q. wislizenii	80-100	4.01	311.27	65	12.9	Auberry	Fresno	100A2/02	762-864	520
Q. douglasii	5-20									
Q. wislizenii	20-50	24.95	1029.18	950	24.2	Stover	Tehama	33B3/23	635-737	340
Q. douglasii	5-20									
Grasses	20-50									
Q. wislizenii	50-80	11.18	1011.96	2295(B)	11.0	Sobrante	Butte	50B2/08	762-864	180
Q. douglasii	20-50									
Grasses	20-50									
Q. wislizenii	80-100	7.18	500.62	686	14.3	Ahwahnee	Fresno	100A2/03	762-864	550
Q. douglasii	5-20									
Q. wislizenii	20-50	10.53	422.15	579(B)	24.9	Sierra	Yuba	50B4/02	762-864	340
Q. douglasii	5-20									
Grasses	5-20									
Q. wislizenii	20-50	8.03	388.51	89(B)	20.7	Wisheylu	Yuba	50A3/03	1143-1245	550
Q. douglasii	5-20									
Grasses	20-50									
Q. wislizenii	5-20	12.96	751.35	847(B)	17.2	Rescue	Yuba	50A3/09	1016-1118	490
Q. douglasii	20-50									
Grasses	N/A									
Q. wislizenii	20-50	8.03	523.47	15	15.3	Tollhouse	Fresno	90C3/03	635-737	820
Grasses	20-50									
Q. wislizenii	20-50	8.85	976.99	969(B)	9.1	Dorado	Calaveras	68D2/04	635-737	300
Q. douglasii	20-50									
Q. wislizenii	5-20	10.60	867.86	675(B)	12.2	Rancheria	Calaveras	69C1/04	1016-1118	430
Grasses	80-100									
Q. wislizenii (shrub)	50-80	8.12	394.23	3019(B)	20.6	Ahwahnee	Yuba	50A3/07	1016-1118	370
Q. wislizenii (shrub)	20-50	8.90	870.56	14	10.2	Sites	Glenn	42D2/02	762-864	850
Q. dumosa	20-50									
Lithocarpus densiflora echinoides	20-50	6.95	328.74	37	21.1	Weitchpec	Humboldt	11D3/08	1778-1880	850
Q. vaccinifolia	20-50									

Table 1--Continued

Plant	Cover	Carbon	Nitrogen	Phosphorus[1]	Carbon-nitrogen ratio	Soil	County	Quad/Plot	PPTN	Elevation
	percent	kg/m^2	g/m^2	mg/m^2	C:N				mm	m
L. densiflora echinoides	50-80	33.48	837.21	438(B)	40.0	Hostler	Yuba	39D4/04	2032-2134	1220
Abies concolor	20-50									
L. densiflora	50-80	13.54	707.81	352(B)	19.1	Salminas	Sonoma	60D2/03	1778-1880	910
Q. kelloggii	50-80	18.35	921.74	791(B)	19.9	Challange	Yuba	50A3/05	1270-1372	820
Q. kelloggii	20-50	6.23	282.62	22	22.0	Neuns	Shasta	24D4/06	1270-1372	550
Q. kelloggii	20-50	11.36	848.58	32	13.4	Guenoc	Sonoma	60C2/02	1270-1372	150
Q. douglasii	20-50									
Q. agrifolia	20-50									
Grasses	20-50									
Q. kelloggii	50-80	6.82	447.11	10	15.3	Mariposa	Shasta	23A4/02	1270-1372	520
Q. kelloggii	5-20	21.82	1713.60	27	12.7	Tyson	Humboldt	26B1/03	1778-1880	1040
Grasses	20-50									
Q. garryana	80-100									
Q. garryana	80-100	16.93	1419.90	52	11.9	Tyson	Humboldt	26B1/16	1778-1880	1010
Douglas-fir	5-20									
Holodiscus discolor	20-50									
Q. kelloggii	5-20									
Douglas-fir	5-20									
Q. garryana	20-50	6.78	433.12	72	15.7	Kilarc	Shasta	15C3/01	1778-1880	580
Q. garryana breweri	20-50									
Grasses	20-50									

root zone where it is taken up by the plant root, the mycorrhiza-root complex, or by microbes for their own use. The microbes have life cycles of a few days at most after which they are decomposed by other microbes. Approximately 0.3 percent (Jensen 1932) of the microbial biomass in each life cycle is left in microbial wall materials (humus), which is highly resistant to decomposition and also high in nitrogen (C:N 10:1). Since there are several turnovers in microbial biomass each season, with 0.3 percent of the nitrogen lost during each cycle, the amount of nitrogen retained in resistant compounds steadily increases. With each microbial generation, CO_2 is produced through respiration and lost from the soil. As the carbon is lost from the litter, the carbon-nitrogen ratio becomes smaller. At ratios of 1:7 to 1:10, the remaining carbon is insufficient to continue decomposition cycles.

The mineralization of nitrogen in leaf litter to nitrogenous forms available for root-mycorrhiza uptake proceeds through many steps. Production of ammonium, NH_4, from amino acids is the first step in the process. The enzymes for ammonification are common in fungi and bacteria. Some plants and many microbes can take up NH_4 as a usable form, some cannot. The transformation of nitrogen from ammonium to the more available nitrate, NO_3, is a two-step nitrification process carried out by bacteria which use the energy released in the chemical process. In the first step, NH_4 is changed to NO_2 by Nitrosomonas group bacteria. In the second step, NO_2 is converted to NO_3 by Nitrobacters group bacteria. Both of these steps are sensitive to almost any disturbance, e.g., burning, plowing (Powlson 1975). The acid pH of oak woodland litter and soil is not preferred by these two groups of bacteria. If NH_4 is the preferred form of nitrogen for plants being raised, the conversion of NH_4 to NO_2 can be blocked naturally by allelopathy (Rice and Paucholy 1972) or artificially by N-Serve which is specific against Nitrosomonas group bacteria (Goring 1967). Blocking this conversion may be a major advantage in preventing the leaching of NO_3 from the site. Pure culture studies have not determined a preference by oak for NO_3-N or NH_4-N. Work on Pseudotsuga menziesii (Mirb.) Franco has shown that this ectomycorrhizal conifer cannot reduce NO_3-N in its larger roots (Li and others 1972); however, subsequent study[4] revealed that the root tips of pure culture P. menziesii are very efficient in reducing nitrate--better even than the intact mycorrhiza. An alternate means of producing NO_3 is heterotrophic nitrification. In this process, a microbe takes an organic compound with a nitrogen compound attached and changes the form of the nitrogen compound without ever releasing it from the attached organic compound. This process continues until the organic compound has an NO_3 attached. The NO_3 is then split off and made available. No free NH_4 or NO_2 is produced in this process (Focht and Verstraete 1977).

Under anaerobic conditions, denitrification, another step in the nitrogen cycle, can occur. NO_3 can be converted to N_2O and N_2 which are subsequently lost to the atmosphere (Focht and Verstraete 1977). The importance of denitrification has not been determined, although this chemical conversion appears to provide a means of nitrogen loss under the litter where the soil is moist with anaerobic microsites.

Nitrogen in the roots (mostly fine) cannot be ignored as an important part of the oak nutrient budget--specifically, 21 percent of the total nitrogen held by an oak (Duvigneand and Denaeyer-DeSinet 1970, Rolfe and others 1978, Johnson and Risser 1974). Yet little information is available on its dynamics. The fine roots are known to undergo seasonal cycles of growth and death, but no data are available on the removal of nitrogen from these roots before death.

More certain are the methods by which roots take up nitrogen. Root hairs, which occupy a limited area, take up nitrogen from solution. Another effective means is through ectomycorrhizae which occur on all oaks (Trappe 1977). The sheath of ectomycorrhizal fungi surrounds the active root tip, isolating it from the soil and preventing production of root hairs. The mycorrhizal sheath has mycelia radiating from it which occupy the soil space more effectively than root hairs from the same length of root. Surface area is increased ten times compared to root hairs. Mycorrhizal mycelia are also much more efficient than root hairs in taking up water and nutrients, including nitrogen. Many plants are unable to survive without the mycorrhizal association unless large amounts of fertilizer are added to make nutrients available, as in nursery operations (Menge and others 1978).

In wildland sites, adding nitrogen fertilizer may not be practical, so a natural source of additional nitrogen is important. In principle, both biological and nonbiological sources of additional nitrogen are available. Both rainwater and atmospheric dust contain considerable amounts of nitrogen. Air provides another usable source of nitrogen derived from volatilization of ammonia, NH_3, from soil, lightning fixation, and industrial sources.

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[4] Trappe, James M. 1979. Personal communication. U.S. Dep. Agric. For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Smog areas are also particularly heavy in nitrogen compounds (Appel and others 1978). Though the amount of nitrogen from these physical effects varies greatly, it cannot be ignored.

Three types of biological input of nitrogen to oaks are recognized. In one method, animals which have grazed elsewhere transport nitrogen into an oak savannah in the form of waste. These wastes are deposited and accumulate under trees which the animals use for shade and protection. The animals remove nitrogen from the same area in the form of acorns, browsed leaves, and grazed grasses. The net loss or gain from this exchange has not been measured, though Holland (1973) contends that removing cattle from an oak savannah does not change the nitrogen accumulation.

The second source of nitrogen accumulation is from roots. Oak root systems extend out beyond the dip line of the canopy where, along with their mycorrhizal associates, they remove nutrients from the entire area and concentrate it around the tree by leaf fall. This should result in a nutrient depletion of the area around the oak and an increase of nitrogen under the oak. But the area just outside the canopy in an oak savannah shows no decrease in nitrogen in the upper soil layers or grass production. Any root accumulation must therefore be from areas below the grass rooting zone.

The third nitrogen source in oak stands is nitrogen fixation. Biological nitrogen fixation can be symbiotic as in legumes and *Ceanothus* or nonsymbiotic as in many blue-green algae and some free-living bacteria species. Symbiotic nitrogen fixation associated with oaks has not been substantiated (Jain and Vlassak 1975). Nor are there reliable estimates of the importance of nonsymbiotic nitrogen fixation in oak woodlands, but it has the potential of being very important. One of the better documented cases of enhanced nitrogen fixation under oaks is with *Q. dumosa* lysimeters at Tanbark Flats, San Dimas Experimental Forest. In these studies, there was no accumulation from surrounding areas and aerial inputs to all lysimeters were the same, but the oak showed increases over the controls in nitrogen content (table 2) (Zinke 1969). This experiment suggests that *Q. dumosa* (and *Eriogonum fasciculatum*) probably enhances nonsymbiotic nitrogen fixation while *Adenostoma fasciculatum* inhibits fixation. *Ceanothus crassifolius* is a symbiotic nitrogen-fixing species. A successful acorn crop provides a major sink of nitrogen which can be transported from the site by animals; however, a good estimate of the amount of nitrogen in the acorn crop is lacking and only poor knowledge exists of the fate of this nitrogen in the ecosystem.

Ecosystems efficiently conserve available nutrient supplies, particularly on low nutrient sites. Few nutrients are lost with recycling. Even the compounds resistant to decomposition are functional here, holding nitrogen which might otherwise be leached from the ecosystem. The rate of movement from one nutrient pool to the next determines the availability of nutrients for growth. Still unanswered is whether nitrogen added to the ecosystem is maintained over a period of time within that ecosystem or lost from it in order to maintain a fixed ratio between nitrogen and some other element.

Phosphorus Cycle

Phosphorus is a nutrient known to be often in short supply, yet essential in the makeup of compounds which transfer and hold energy, adenosine triphosphate (ATP). Amounts present in oak sites vary considerably (table 1). Weibull distribution[3/] of phosphorus values for *Q. dumosa* soil in California (fig. 5) provide a comparison of extractable phosphorus in the top 5 cm of soil for a given site.

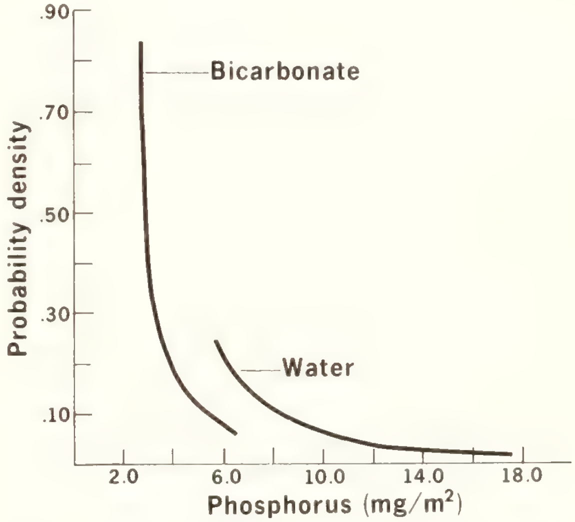

Figure 5--Weibull function for water-soluble and bicarbonate-extractable phosphorus for California *Quercus dumosa* soil (0-5 cm) (Data supplied by Paul Zinke, University of California, Berkeley).

Available phosphorus is often the problem, and not total phosphorus. Zinke's Weibull probability distributions furnish two different measures of available phosphorus. Mycorrhiza provides one means whereby the availability problem is overcome. Root hairs inefficiently occupy a total soil volume and phosphorus diffuses very slowly in soil. In contrast, mycorrhizal mycelia very capably occupy this

Table 2--Nitrogen accumulation in the San Dimas lysimeters in 13 years (after Zinke 1969). Values are g/m^2 of nitrogen.

	Original Soil	Barren	Cover Type			
			Af[1]	Eff[2]	Qd[3]	Ccr[4]
Vegetation	0	0	5.2	10.6	6.1	29.6
Litter	0	0	3.2	30.0	17.9	32.4
Mineral soil to 122 cm	318.0	283.8	278.5	318.8	343.6	320.1
Total	318.0	283.8	286.9	359.4	367.6	382.1
Change		-34.2	-31.1	+41.4	+49.6	+64.1

[1] Af = *Adenostoma fasciculatum*
[2] Eff = *Eriogonum fasciculatum*
[3] Qd = *Quercus dumosa*
[4] Ccr = *Ceanothus crassifolius*

soil volume. Mycorrhizal fungi are very productive in phosphorus uptake. Citrus research shows a great increase in uptake efficiency when mycorrhizal fungi are present (Menge and others 1978).

Availability of phosphorus is also changed by the relationship between pH and phosphorus solubility. More than 30 years of lysimeter measurements in the San Dimas Experimental Forest show an increasing amount of available phosphorus which correlates with decreasing pH.[3]

Fertilization

Fertilization is currently an oak woodlands management technique practiced outside of California to increase production. Nitrogen fertilizer can be added to a site in two ways. Mineralized nitrogen fertilizer can be added to a site, but on a large scale this addition to low revenue producing oak woodlands is economically impractical; however, this may be very feasible in ornamental operations. A few principles are clear from fertilization work done in the eastern United States. Most studies show a response of eastern oak to nitrogen, but an N-P-K mixture gives a superior response (Auchmoody 1972, Farmer and others 1970, Broadfoot 1966, Buckley and Farmer 1974, and Grandy and Pope 1978). The fertilization response lasts 5 to 10 years (Buckley and Farmer 1974). Fertilizer recommendations have to be made individually based on the unique requirements of each site. The implications of eastern United States oak fertilization experiments on western oak species is unknown. Oak fertilization and nitrogen cycling in the eastern United States have been reviewed by Patric and Smith (1975), but no similar work exists for western oaks.

Microbes

Where oak roots are infected with efficient strains of mycorrhizal fungi, much lower concentrations of available nitrogen and phosphorus can be tolerated. Enhanced nitrogen availability through nonsymbiotic bacterial nitrogen fixation may also be possible in the future. These two types of microbes in particular need to be considered to preclude oak sites from reverting to grasslands or other non-oak areas. Nursery addition of good mycorrhizal strains could solve many problems (Trappe 1977).

The amount of nutrient (such as nitrogen) on a site may also be important in determining the spacing of oak trees, and may limit the biomass that a given site can support. Phosphorus is particularly important because no biological way exists to fix this nutrient. The amount which is available on a site is all the oak woodland will have. Fertilization may figure importantly in cases of low soil phosphorus.

Another impact of mycorrhiza on oak woodlands is the production of subterranean fruiting bodies, or truffles (Gilkey 1916, 1954). Truffles are important components of a rodent's diet (Maser and others 1978, Stienecker and Browning 1970) and are highly valued by Europeans for their flavor. Research is currently trying to introduce the European mycorrhiza onto California oak for commercial production of truffles which would give oak woodlands a high economic value.[5] In 1978, the European black truffle brought $250 to $400 per pound. The production of edible truffles promises to provide more economic return than oak wood, and could increase wood production and provide a steady return until logging age.

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[5] Trappe, James M. Pers. commun. 1979. Mycorrhizal applications in ecosystem management. U.S. Dep. Agric. For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Native truffles also may be edible. Q. dumosa at Kitchen Creek, San Diego County, California, has produced specimens of four different truffles: the Ascomycetes Geopora clausa spp. Californica (Gilkey) Bards and Tuber rufum var. nitidum (Vitt.) Fischer, and the hypogenous Basidiomycetes Gautieria parksiana Zeller and Dodge and Hysterangium spp. These fruiting bodies seem to be common in the upper soil layers and are probably important to rodents and may be usable for human consumption.

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Quercus kelloggii

Oaks and the California Landscape[1]

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Abstract: Native oaks are important visual elements in the California landscape. Their significance is suggested by statewide distribution, by historic association, and the variety of visual roles played. Much of our local and regional landscape character is identified with different oak species and their visual arrangements; conservation of that character helps maintain scenic amenity. Oaks and landscape are discussed in regard to highways, recreation places, and urban forests. Some landscape research needs on native oaks are posed.

INTRODUCTION

Native oaks play a significant role in the California landscape. Oaks and their typical visual arrangements contribute to the distinctive identity of local and regional landscapes. Indigenous oaks are both numerous and widely distributed. Historic accounts recognize the relationships of oak trees with such places as Oakland and with early Spanish exploration. The maintenance of the esthetic character of California landscapes, some of it intimately dependent upon oaks, should be recognized as one part of environmental quality protection.

California oaks, as a group, occur in several sets of visual relationships which typify particular regional landscapes. Three distinctive oak patterns contribute to scenic quality. Two of the patterns consist of highly contrasting mosaics of grass and oak woods with strong light to dark color contrasts. In spring they display a marked color brilliance. One of these two patterns is the oak savannah, a continuous woodland spread of scattered oaks, variable in density, through which the simple and flowing ground plane of grass remains apparent. The other pattern is a discontinuous mosaic of oaks in solid wedges, stringers, or whole slope faces interspaced with clear grassland patches of various shapes. This contrasting pattern of distinct oak and grass areas can usually be correlated to facets of the topography and to exposure. The third major pattern is that of occasional oaks--especially black oaks (Quercus kelloggii Newb.) --either grouped or alone within the dominant continuity of the mixed conifer forest. This is a more subtle pattern than the preceding two but the scattered presence of oaks makes local cells of contrast in color and light intensity compared to the more sombre, more abundant conifers. These particular oak patterns have special value in their contribution to scenic quality that has regional identity. They should serve as physical models to influence the form of development changes. Urbanization and land use conversions are prone to make every place look similar, leading toward mediocrity in our surroundings. Retention of California oak landscape as a physical, visual resource and responding to it ultimately serves environmental quality more broadly. It is logical to start by conserving local and regional amenities.

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Kuchler's vegetation map (1964) suggests we are never very far away from native oaks. The whole rim of the Central Valley, save a small gap at the south end, is oak woodland. That ring is about 900 miles long, includes some five oak species variously distributed north to south and east to west, but runs heavily to blue oak (Q. douglasii Hook & Arn.). Then in the northern Coast Range from Eureka to the south of San Francisco - some 250 miles--we find oaks among the dominant trees within the mixed evergreen forest (Kuchler's type 29). The southern Coast Range--Monterey to Santa Barbara--is again characterized by the California oak woods type. Canyon oak (Q. chrysolepis Liebm.) and black oak,especially the latter, are visually important though subordinate counterpoints within the very extensive mixed conifer forest of the Sierra-Cascade west side, the Klamath Mountains, and the north end of the Coast Range. The presence of oaks does not end there,because pockets of them grow on the ridge east of San Diego,while at the extreme north end of the state, the Oregon white oak (Q. garryana Dougl.) makes a token appearance. The Central Valley, particularly the Sacramento portion, has its oak hummocks and riparian stringers, the last suffering serious reductions compared to an earlier time. The only sizeable part of California's landscape without the visual component of oaks or remote from it is the southeastern desert country.

Some place names of the State suggest historical or cultural values based upon oaks being conspicuous in certain landscapes (Gudde 1965). The Spanish were more discriminating than later settlers, distinguishing live oak (encina) from the deciduous oak (roble). Part of the city of Oakland was originally called "Encinal de Temescal" (Liveoak Grove by the Sweathouse), a name reflecting Spanish, Mexican, and Indian influences. Both the earlier Spanish and the later Anglo-Saxons nonetheless observed that oak groves were distinguishing elements of this particular landscape. Paso Robles (Pass through the Deciduous Oaks) in San Luis Obispo County was first named by Padre Pedro Font in 1776, later becoming the title of a land grant and was finally adopted as the city name in 1889. Two other towns named for oaks in the 1870's refer to entirely different species: Oakdale, Stanislaus County, memorializes interior live oak (Q. wislizenii A. DC.); and Oakville, Napa County, recognizes its big valley oaks (Q. lobata Nee). It is apparent from these few examples that oaks have strong enough visual images to be perpetuated in names.

The maintenance of local or regional landscape character built upon native oaks represents an extremely important and more effective means of conserving scenic amenity than any attempt to provide a man-made substitute. The original landscape of an area is normally an extensive combination of regionally typical landforms, vegetation patterns, and water forms. To this will be added new land use patterns, either urban or rural; but in usual situations no overall man-made substitute takes the place of the earlier landscape. Physical signs of human activities,including clearing, grading, construction, and new planting, are more apt to be seen as fragmenting rather than integrating. The use of introduced trees is not automatically condemned,because it can be both efficient and attractive; but the sensitive use of indigenous oaks, along with their perpetuation in place, is an important means of integrating new development with the broader surrounding landscape.

Highways

Highways are a primary way of showing us the landscape. They pass through the country in one of two ways. They can thread through the landscape in a way conforming to the landforms and tree cover typical of a locality, combining road and countryside into a satisfying experience. Or the highway can more literally blast through terrain and vegetation providing a road foundation without apparent regard for surroundings and isolating road from place. Where the components and scale of the landscape fit the scale and design of the highway, there may still be failure to make compatible relationships with the local vegetation mosaic. Not all highways include roadside plantations, but all roads pass through the landscape. Some examples may suggest how California oaks can relate to highways and countryside.

Freeway 24 leaves Walnut Creek and approaches Oakland through several ranks of hills. The dominant native vegetation is live oaks in draws and on shadier slopes while drier slopes are valley oak woodland or mosaics of oak-chaparral. The roadside within the right of way is planted in a complete way, a relatively normal procedure for an intensively traveled route in an urbanizing area. The plantings are eucalyptus and pine with introduced shrub cover which do not recognize the adjacent and distinctive native cover of oaks, grassland, and chaparral. The plantation solves certain functional problems, such as light-motion screening and erosion control. Yet the concept of the roadside plantings totally excludes any influence by the original landscape or linkage with it. A visual connection with the surroundings could have been made with judicious placement of oaks, even while allowing use of certain subordinate exotics if practical necessity demanded it. This particular freeway planting addresses certain functional problems, but the amenity provided is isolated from the broader landscape seen from the road.

In a related counter example, live oaks are the major roadside trees planted along Highway 101 in the vicinity of Santa Maria. Roadside oaks correspond directly with the scattered oaks of the adjacent flat, then together they make a visual linkage with the local hillside mosaic of live oak-chaparral.

Highway 101--the Redwood Highway--between Petaluma and Santa Rosa runs through open agricultural country with considerable residential development. The native landscape of flatter parts is grassland with widely spaced valley oaks. Hill slopes in the distance are grassland or evergreen forest with live oak (Q. agrifolia Nee) dominant. This being the Redwood Highway, widely spaced clumps of redwood are planted along both sides of the roadway. Redwoods were never a part of this landscape. Those that are now planted grow in an inhospitable climate of summer drought, heat, and wind. Tourism and the strength of a name have taken precedence over a more appropriate useage of valley oaks which belong in this place. Redwoods will occur naturally along the highway further north, a canopied landscape infinitely more impressive than this artificial plantation.

South of Red Bluff, Interstate 5, the high-speed freeway passes through rolling low hills covered with blue oak woodland, a relatively small-scaled landscape. By modifying horizontal and vertical alignments to fit the hills and adoption of a variable median area, the separated opposing lanes approximate the visual scale of a two-lane road. Continuity of the blue oak woodland is maintained within the median as well as along the right-of-way boundary. The outside edges are cleared irregularly rather than following the absolute edge of the fenced line. By contrast, the freeway approaching and leaving these blue oak hills runs with a straighter alignment through flatter, open country. This kind of skillful highway design made responsive to a local landscape gives the traveler an interesting sequential change in an otherwise rather monotonous stretch of road. The character of the oak woodland is observed and no other roadside plantings are needed.

The general policy for planting along California highways is to be guided by the vegetation adjacent to the right of way. It is a matter of design judgment as to what degree there is response to the local man-altered landscape or to the native regional surrounding. California oak landscapes are distinctive and merit consistently sensitive response in highway design and construction phases.

Parks and Recreation Places

For parks and recreation places where oaks dominate the landscape, two questions about visual quality arise. Are new plantings made with appropriate attention to surrounding oaks? Does silvicultural management assure perpetuation of oaks?

A century ago, Grinding Rock State Park in the Mother Lode was a favored spot where the Miwok Indians gathered acorns from the valley oaks and black oaks. Farming later modified the area by clearing. Now old and mature oaks appear as landmark trees. Some of the oldest are decadent and falling apart. Younger oaks grow in rather dense woods with some ponderosa pine and incense cedar. There are almost no oaks of intermediate age and size. The purposes of the modern park use will be served well by maintaining large, rather widely spaced oaks in sizeable openings bounded by dense pine-oak forest. The park is a handsome oak landscape reflecting an early history of Indian use. Yet it will not remain as it is, and a tree replacement program is needed. The problem posed is one of recreational silviculture coupled with spatial design to suit contemporary and future park needs. The model to be followed is present in the landscape as it may now be seen.

Glencliff campground in the Cleveland National Forest is in a flat with large and scattered canyon live oak. The oaks are conspicuous for their size; their darkness contrasts to lighter enclosing hillsides with thin and sear chaparral. While canyon live oaks are the primary visual key to the local landscape, they also afford the functional amenities of shelter and shade; the local climate is seasonally harsh. With the openness of oak woods being less than ideal for a campground, plantations of Arizona cypress have been introduced for screening. The pointed and glaucous forms of the cypress have little in common with the original surroundings, are visually competitive with the oaks, and can not give the shelter the oaks do. As an alternative--and in response to what may be seen--it would have been possible to use heavy plantings of canyon oak, first to give screening and later to grow selected oaks into tree form.

At one level of consideration, the introduced cypress at Glencliff are satisfactory in their growth and in improving the recreational site. In a more urban place than this one, designed contrasts combining native and introduced vegetation may be accepted as interesting and appropriate--the context of a man-modified environment. At another level of consideration, this example shows no appreciation for the special visual character of the surroundings, a point of principle that bids ill for protecting a particular wildlands environment.

Oaks in Urban Forests

In a recent paper on urban forestry emphasizing visual landscape values, I defined "urban forest" as the general impression of forest within the city seen both close by and in the distance (Litton 1978). To this should be added the attendant values of varied uses which apply to urban systems of combined forested and open spaces. Oaks in the urban forest are apt to be remnants of an earlier rural landscape,and as such, offer particular advantages. Since oaks normally occur either as isolated individuals or massed into woods, they can be considered in these two ways in towns or cities.

Oak Woods

As part of the visual landscape, oaks are arranged (or were so originally) in discernable patterns of woods intimately reflecting the forms and aspects of local terrain. In turn, the local scene joins a larger regional landscape. So oaks can contribute directly and importantly to the amenity of the city, both locally and as tied to broader surroundings. In cities such as Berkeley and Santa Barbara, live oaks are found grouped in stringers or wedges of upper watersheds and defiles, massed on steeper upland faces and adapted to sites with advantageous soil-moisture conditions. Such upland areas offer special visual values to a city because of their possible continuity and their high degree of visibility from lower parts of town. That wooded continuity can be maintained while containing low density housing if carefully done or by concentrating pockets of higher density housing separated from areas of oak woods. Conservation of such oak areas can succeed only with early recognition of their value, and sensitive planning and design.

Other advantages of oaks in grouped patterns extend amenity values into other inherent relationships. Their adaption to place enhances survival potential. At the same time, massed groupings are logical subjects for application of silvicultural management which can assure their future. Yet judging from the Berkeley campus of the University of California, the concept of maintaining oaks by silvicultural means is not evident. Photographs from the year 1900 show remarkable old and mature live oaks, perhaps 200 or more years old at that time. Having reached the end of their life span, none of these old giants remain on campus. Even so a form of recreational silviculture applied to existing oak groves and coupled with control of irrigation could give this campus some historical ties to an earlier condition.

Connected functional and aesthetic purposes are also served by oak woods. They include urban wildlife habitats, offering sanctuary to birds and small mammals, and the esthetic opportunity for wildlife observation. They provide watershed protection by slowing up urban runoff and retaining water. Oak groupings, if of sufficient size and continuity, offer desirable opportunities for recreational access, the location of limited park facilities, and connective routes. A function of oak management, coupled with open space design objectives, may be the extension and consolidation of oak woods.

Single Oaks

Individual and isolated oaks in the city--largely remnants of an earlier time--appear to have greater threats to their survival than do oak woods. Sheer competition for space is the central problem, but individual construction activities as well as the collective impacts of urban development take their toll of native oaks. Carelessness and ignorance contribute, but even the most careful measures meant to protect individual trees can eventually fail. New oaks planted after construction may have the best chance for successful growth in altered site situations.

Separated and single trees have visual influence only over local scenes--a different scale relationship from that of massed oaks. Only if widely spaced trees are sufficiently repeated do they endow notable character to a town--a condition fulfilled by the valley oaks of Paso Robles. Even so, because oaks are generally long lived, the enduring dominance of a single large tree in the local landscape is significant and without substitute.

Oak species have life spans ranging from 150 to 300 years (Harlow and Harrar 1950). Therefore, protection of all but decadent individuals is worthwhile. Problems of maintaining single oaks in town, for parks or other purposes, can be represented by the example of constructing a single building near an oak or oaks. A house may be architecturally designed to fit the focal feature of a single fine oak, with the tree working as a central link between house and garden. It is a grand and simple idea. The execution needs care at every step, followed by proper water and garden management. Conventional experience indicates that avoiding any changes within the drip line of an oak is the most desirable way to be safe, a safeguard frequently violated. The structure must fit the tree level; grading must be minimized. House walls cannot crowd the tree. Foundation design to avoid root damage may require bridging or piers in lieu of continuous walls. Any filling or paving within the tree canopy area can be threatening (decking, permeable paving or sharply limited paving may succeed). Elaborate systems of maintaining an air-water interface between original ground grade and imposed fill are unlikely to succeed except temporarily. Roof water has to be removed independently from the tree root zone, and any under-canopy gardening should be modeled to follow the preexisting condition of the microsite and its climate. A successful end result means careful attention to a full array of factors.

Contemplating the place of oaks in urbanizing situations suggests several conclusions. What we may know about oak protection and culture is neither assembled in accessible form nor is it available for every day use. What we do not know about oaks and their use in landscape is considerable and a desirable research subject.

Landscape Research on Native Oaks

The need for Landscape research on California oaks can be posed by such questions as: How can we maintain oaks in urban places? Can forms of recreational silviculture be developed for perpetuation of oak woods? Would it be useful to find out how oaks may be commonly appreciated in certain California landscapes? Would the assembly and dissemination of current information about oaks be useful to citizen's groups? To urban planning departments? To environmental planners and landscape architects?

Maintaining oaks in urban places means protection of individuals as well as grouped trees. We need to understand how particular species have been affected, and to what degree, by the urban stresses of grading and paving, changes in surface and groundwater supplies, and by microclimate modifications. It appears, for example, that valley oaks are more sensitive to paving over the root zone than are live oaks, but such generalizations are not specifically helpful and may be misleading. Oaks, according to species, have different but relatively long life spans; more accurate prediction of future life has a bearing on adoption of protective measures. Does the urban environment have a material effect on oak longevity? Oaks seem to grow slowly, and this assumed rate may be a misguided reason given for discouraging their planting. We actually know little about growth rate of oaks in either urban or rural places; it may be faster than assumed and cultural practices could enhance growth rate. A slower growing oak as a street or park tree offers a real advantage over faster growing trees in needing a minimum of pruning maintenance. Avoiding the impacts of some pruning practices used on fast growing trees suggests both economic and esthetic bonuses. Cities with trees massed in woods could perpetuate those trees by the adoption of silvicultural techniques. Even so, we do not know about how large an aggregation of oaks, or in what condition - may make it a suitable subject of silvicultural research.

Experimentation with recreational silviculture, that silviculture oriented to landscape resources, may best start in rural and wildlands areas. Grinding Rock State Park has been suggested as an appropriate place for such research. Bringing together several professional disciplines is needed--the plant ecologist-forester, the park administrator, the landscape architect. And the social scientist is called upon to ascertain public values and to communicate with a public which can be hostile to misunderstood manipulations in park landscapes. It takes time for an interdisciplinary research and planning team such as this to integrate their varied capabilities and to identify goals. Silvicultural manipulations take time to show effects. A long-term policy is needed to assure that the undertaking is not scuttled by neglect or adoption of new, short-view policies.

In conclusion, the identification of oak landscape values within this paper has been based upon personal, professional judgment. To confirm or deny the elements of professional landscape judgment and to discover other esthetic values that interested communities may have about the outdoors is possible only with social science research. This kind of research in wildlands is politically unpopular and difficult to fund. Yet it is needed to show what degree of public support may exist to maintain the environmental qualities of oak landscapes and their regional identity.

We as resource managers should strive to bring together knowledge now fragmented and spread out among many different individuals. Information about California oaks is not readily available in any concentrated or easily available form. Certainly many individuals--researchers, academicians, planners, foresters, landscape architects, to name some--have information about oaks based upon research and observation. A "state of the art" publication about oaks would fill a void at this time. Such a working paper would be helpful to researchers, professional practitioners, and local planning/open space agencies. As an example, there appears to be much popular interest in native plants; sometimes it takes a naive form, suggesting that all nativesare good plants,presenting a heaven-sent solution to maintenance-free landscapes. We know native plants, including oaks,are an interesting class of plants which demand certain conditions for successful growth, but research priorities about oaks need identification. A working paper should also be helpful in revealing a constituency interested in oak use and protection along with what they need to know. Although a "state of the art" publication represents a modest kind of proposal, it should be both immediately informative and suggestive of what we need to find out about native oaks in the California landscape.

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Quercus agrifolia

Measures That Can Help Offset the Detrimental Effects That Urban Development Has on Oak Trees[1]

Paul A. Rogers[2]

Abstract: Land development is seriously encroaching upon our southern California oak woodlands. Urban development not only creates an unnatural environment, it also impacts these oak trees. Unless careful corrective measures are taken during construction, the trees ultimately decline and die. The effects that construction has on oak trees with regard to loss of air, water, and nutrients are discussed. The loss of roots and/or top foliage during construction is of major concern. Solutions center on the preservation of driplines during construction, special procedures for grading cuts and fills around oak trees, the use of specialized soil/air drainage systems, and compensatory pruning and fertilization of impacted trees. This paper covers the practices currently used to preserve oak trees in highly developed areas.

All of us appreciate the native oak trees and are familiar with their majestic beauty. But as man continually develops their natural habitats in the coastal valleys and foothills it is inevitable that he will encroach upon them. This encroachment not only creates an unnatural environment for these trees but it often seriously impacts them unless careful corrective measures are taken. This paper will provide an overview of some of these problems and offer some mitigating measures that can help to offset them.

Urban development continually encroaches upon the oak trees' well-being by the construction of homes, roads and utility lines. Additionally, grading changes most seriously impact oak tree roots by both cuts and fills. Ultimately natural drainage courses are changed such that the tree is now forced into an unnatural environment. From this point on, decline is usual, and it is an eternal battle to try to save a tree in this condition. For instance, drainage water from a car-wash rotted the roots of one oak tree so extensively that we were able to pull it straight out of the ground with a crane.

The oak problem in many sites to be developed begins with the army of heavy equipment that is used during grading. This is damaging to the trees, as soil is removed and roots are either severed or filled over and compacted. Additionally, water tables are changed and trees are often neglected during the entire construction period. Compounding this is the dust that accumulates on the leaves. Compaction is often further increased as the trees offer shade to construction workers and their vehicles.

Once grading is completed the construction of buildings also takes its toll on the trees. Utility trenching severs roots and often such trenches are left open for extended periods of time.

Building construction often requires removal of some of a tree's upper structure. Disfiguration by limb breakage is a common occurrence. When pruning is performed, large limbs are often removed or the tree may become somewhat pollarded, which obviously destroys its beauty. Such severe pruning further creates

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[1] Presented at the Symposium on Ecology, Management and Utilization of California Oaks, June 26-28, 1979, Claremont, California.

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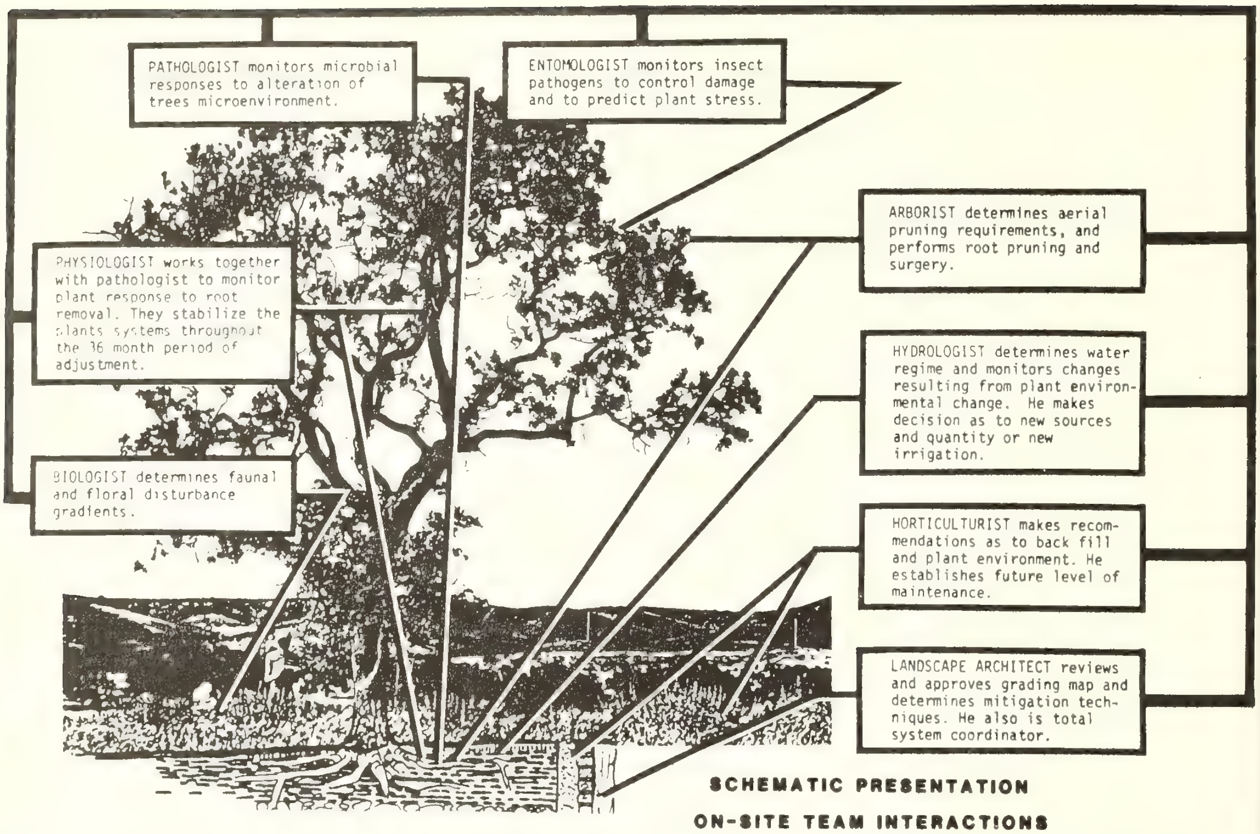

PATHOLOGIST monitors microbial responses to alteration of trees microenvironment.
ENTOMOLOGIST monitors insect pathogens to control damage and to predict plant stress.
PHYSIOLOGIST works together with pathologist to monitor plant response to root removal. They stabilize the plants systems throughout the 36 month period of adjustment.
BIOLOGIST determines faunal and floral disturbance gradients.
ARBORIST determines aerial pruning requirements, and performs root pruning and surgery.
HYDROLOGIST determines water regime and monitors changes resulting from plant environmental change. He makes decision as to new sources and quantity or new irrigation.
HORTICULTURIST makes recommendations as to back fill and plant environment. He establishes future level of maintenance.
LANDSCAPE ARCHITECT reviews and approves grading map and determines mitigation techniques. He also is total system coordinator.
SCHEMATIC PRESENTATION
ON-SITE TEAM INTERACTIONS

Figure 1--Maintaining healthy oak trees on developed sites requires input from several disciplines.

problems with growth flushes and the subsequent witches broom or powdery mildew diseases.

By far the greatest problem we encounter from development around oak trees are those situations where soil is filled at the trees' bases. This is critical for air and water drainage. Oftimes such fill soil located at the tree's trunk will retain moisture and in time will cause rot and eventually undermine the tree. One declining tree that we investigated had seven feet of fill at its base. After its soil was removed we found that the basal area had already rotted two-thirds around the trunk. It appeared that former construction had damaged the tree trunk and that the presence of soil and its moisture retention had accelerated the demise of this tree.

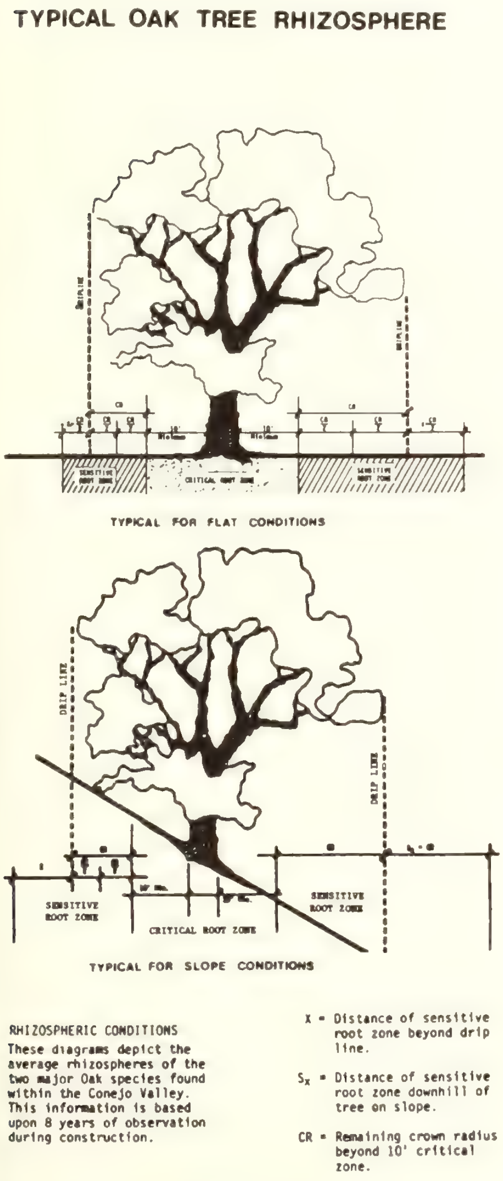
Once site development is completed the tree problems do not end. This is a critical time for them. Recognize that the trees have been removed from a natural environment, weakened by development and are now located in an artificial environment. Such an environment subjects them to overirrigation, planting at their bases, improper pruning, and perhaps further compaction. In time, it is inevitable that such trees will decline and eventually die

So, those are the problems -- at least some of them that confront us. It is possible to have successful stands of oak trees in an urban scene. We have many such situations but it does require expertise and money to achieve success. Such an effort encompasses the interfacings of several disciplines (Fig. 1). A discussion of some of these follows.

A good horticultural evaluation of all trees present on a proposed site is most important. Such an evaluation essentially separates the trees into removal and preservation categories. Some times we try to save trees that shouldn't be saved. This is a costly decision because tree removal after construction has been completed is considerably more expensive than earlier removal.

A good horticultural evaluation encompasses an investigation of all tree parts by a knowledgeable person. Upper structure should be examined for cavities, physical weaknesses and possible pest problems. Such pest problems may have to be identified by a pest control advisor and by pathological testing.

Basal parts of the tree must be inspected in detail. Trunks should be examined for cavities or the presence of excessive amounts of fill soil. Not to be overlooked are the trees' roots. Where are they? Are the trees deeply rooted such that construction may not seriously impact them (Fig. 2)? Are they diseased?


TYPICAL OAK TREE RHIZOSPHERE

RHIZOSPHERIC CONDITIONS
These diagrams depict the average rhizospheres of the two major Oak species found within the Conejo Valley. This information is based upon 8 years of observation during construction.

X = Distance of sensitive root zone beyond drip line.

S_x = Distance of sensitive root zone downhill of tree on slope.

CR = Remaining crown radius beyond 10' critical zone.

Figure 2--Typical distribution of root zones under the canopy that are "sensitive" or "critical" to the trees' well being.

These examinations must be performed and recorded in order to accumulate as much information as possible on each tree. Such evaluations should include tree sizes relative to height and spread, and root locations so that developers can plan around them to avoid serious impaction.

When evaluating the impact of construction on trees, building and landscape are of key importance. We try to save as many trees as possible and to lessen the impact of construction on them. For example, rather than construct a concrete wall which would disturb a tree's root systems, a wooden fence may suffice, as it would not require trenching for a foundation. Relocation of building pads or utility trenches can also be of great benefit to a tree. Perhaps several utility lines could be placed into one or two trenches -- thereby reducing tree root loss.

Pre-job conferences with all contractors can be of great benefit. Such meetings can enlighten these people about the trees and their care. Also the use of fences placed around oak tree drip lines can assist in assuring that compaction and the dumping of debris is lessened.

Ideally it is best to have all surgical or pruning work done prior to construction. This permits ease of arborcultural work and tree pruning performed often balances the roots lost during construction.

Should special tree wells, watering or feeding be required this is also an excellent time to perform them.

It is important that a knowledgeable person be present or available during all phases of construction. Such a person (usually a horticulturist or arborist) would be monitoring the trees and ensuring that they are properly maintained. Also such a person would have the capability to establish programs for future levels of maintenance.

In summary, then, protecting our oaks is the implementation of a complete program (Fig. 3). Such a program involves pre-site planning, horticultural evaluation and data collection design, and preparation and care of the trees prior to, during, and after construction around them. This program may interface many disciplines such as landscape architects, pathologists, entomologists, horticulturists and others as illustrated. Once these program items have been put into effect, we will be able to have successful oak stands within urban development.

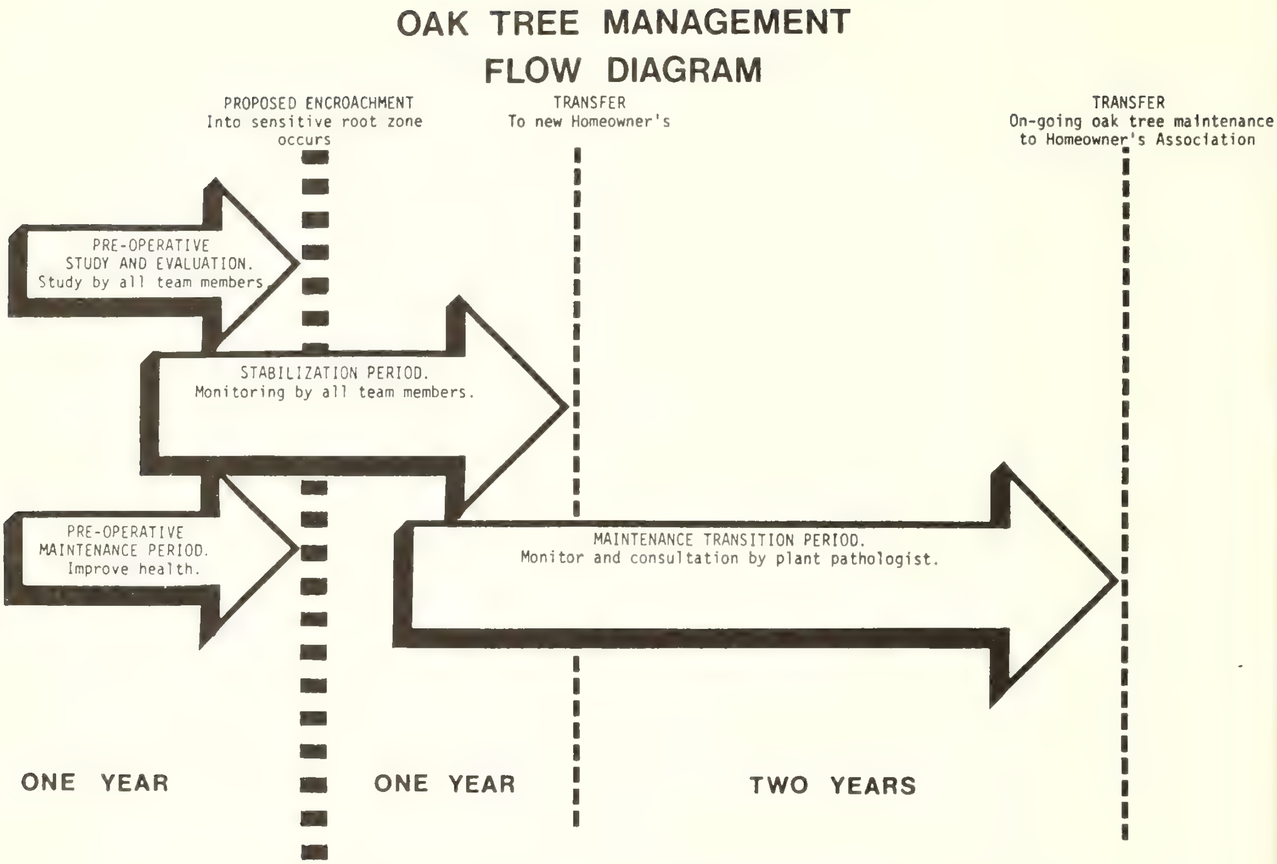

OAK TREE MANAGEMENT
FLOW DIAGRAM
PROPOSED ENCROACHMENT
Into sensitive root zone occurs
TRANSFER
To new Homeowner's
TRANSFER
On-going oak tree maintenance to Homeowner's Association
PRE-OPERATIVE STUDY AND EVALUATION.
Study by all team members.
STABILIZATION PERIOD.
Monitoring by all team members.
PRE-OPERATIVE MAINTENANCE PERIOD.
Improve health.
MAINTENANCE TRANSITION PERIOD.
Monitor and consultation by plant pathologist.
ONE YEAR
ONE YEAR
TWO YEARS

Figure 3--Flow diagram illustrating the critical periods of an oak tree management schedule.

Quercus lobata

Aspects of Water Relations in Coast Live Oaks and Valley Oaks Subjected to Root Damage from Land Development Operations[1]

Stephen W. Roberts[2/] and Robin L. Smitn[3/]

Abstract: Xylem pressure potentials and stomatal conductances were intensively monitored in individuals of coast live oak (*Quercus agrifolia*) and valley oak (*Quercus lobata*) in order to assess short-term effects on the tree water system resulting from root pruning and land grading operations. Increased water stress was measured in affected trees. The most negative potentials were approximately -30 bars in September and October in both species. Stomatal conductances were typically quite low (0.02 to 0.10 cm s^{-1}). Patterns of stomatal activity were measured which appeared to limit water stress. It was concluded that these oak species possess adaptations which may enhance survival following root system disturbances such as may occur during land development operations.

INTRODUCTION

Southern oak woodland communities in southern California are being increasingly utilized by land development projects. The principal tree species in these communities are vegetationally, ecologically, and aesthetically important community components. In the area of Thousand Oaks, California, *Quercus agrifolia* (coast live oak), *Q. lobata* (valley oak), and other oak species have undergone significant habitat modification from recent grazing and farm practices and currently by changed land-use patterns from land developments. The survival and reproduction of oak trees in this rapidly changing environment is of concern to individuals working in the conservation and management areas. These individuals now face important challenges in regard to appropriate treatment of these oak communities.

The oak trees in the study area represent species which have evolved a set of responses to external water availability under environmental constraints which have operated over evolutionary time. Changing land use patterns which alter the water regime for these plants represent an important perturbation to a key environmental factor. In addition, the time scale of such perturbations is short relative to the generation time of the trees, which may live for hundreds of years. Thus, individual trees with a set of response properties largely determined by past evolutionary history must now survive and reproduce under new conditions which may be quite different from conditions under which those properties evolved.

A working hypothesis of this study is that site modification by land development will alter site water balance. The changed water balance should in turn affect a variety of physiological processes in the oaks and other plants. These effects may be detected in changed tree water use patterns through altered leaf stomatal conductances, which govern the exchange of water vapor, CO_2, and other gases, and altered patterns of leaf water potentials, which are related to the ability of plants to extract soil water and which affect rates of a

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[1/] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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number of metabolic processes. This study was designed to test this hypothesis and in so doing provide needed data on water relationships of Q. agrifolia and Q. lobata. These data would then allow a preliminary evaluation of some effects of site modification such as grading, drainage alteration, soil loading by structures, irrigation, and other activities associated with land development.

METHODS

The study site was located on the development known as Ben Johnson's Fairway Homes, near Thousand Oaks, California. The site is on gently rolling terrain dissected by small drainages and intermittent streams. The property is part of North Ranch, and the study area had been used in the past for grazing cattle.

The trees studied were all mature individuals roughly 80 to 100 years old. Tree heights were generally between 20 and 30 feet. The trees for which data are presented are characterized briefly in table 1. Water relations were measured in individuals of Q. agrifolia and Q. lobata which had varying portions of the root system removed as a result of building retaining walls near the trees. The fraction of roots which were removed could not be quantified because the root distributions of the individual trees were not known. However, an approximation of root system disturbance is given by the use of an index as described shortly. The walls involved vertical cuts typically 4-6 feet in depth, located approximately 8-10 feet from the base of a tree. Measurements were also made in undisturbed control trees as a reference by which to gauge the effects measured in the disturbed trees. A crude index of disturbance to the root system was obtained by measuring the length, depth, and distance from the tree base of the trenching cuts. These values were then incorporated into a "root disturbance index" (RDI) using

$$RDI = \sum_{i=1}^{N} D_i \ (L_i/R_i)$$

where D is the depth of the cut, L is the length of the cut, and R is the radial distance of the cut from the tree base. All measurements are in inches. Measurements were taken in increments around each tree and summed to give the total RDI. These indices are given in table 2. The effects of these root-cutting and grading operations were assessed primarily through measurements of xylem pressure potentials. Pressure potentials were measured using a pressure chamber of the type described by Scholander et al. (1965) and by Ritchie and Hinckley (1975). Stomatal diffusion conductances were also measured with a porometer of the type originally described by Kanemasu et al. (1969). During days of tree water relation measurements, air temperature and wet bulb temperature were measured with a shaded sling psychrometer. Photosynthetically active solar radiation (PAR) was also measured. Soil psychrometers were installed to measure soil water potentials at 5, 20, and 60 cm depths.

Table 1--Brief characterization of study tree settings.

Individual tree	Comments
18, 19, 20 (QL)	Located on a ridgetop, in well-drained, somewhat sandier soil than is typical at the study site.
787 (QA)	Located off the study site, used as one of the control trees.
89, 92, 93, 94 (QL)	Located in close proximity to each other on gently sloping terrain typical of the study site.

Table 2--Root Disturbance Index measured for the trees in this study.

Tree	Root Disturbance Index (RDI)
	—— Inches ——
QL-18	0, 298[1]
QL-19	510
QA-89	419
QA-92	0, 1129[1]
QA-93	340
QA-94	229
QA-787	0

[1] When serving as a control tree, RDI = 0: final RDI was calculated following grading operations.

Daily courses of leaf water relations were measured beginning at dawn. Pressure bomb leaf samples were obtained using a climber who extensively sampled all levels and exposures in the tree canopy. These data indicated that a major source of variability in pressure potentials was the recent previous condition of exposure of the leaves to solar radiation. Analysis of these measurements revealed that the horizontal variability was as great as the vertical variability in the canopy. Thus, subsequent sampling was concentrated at lower canopy levels, allowing more trees to be studied. Leaves were systematically sampled from the four compass directions. While the within-canopy variation was often significant, mean values and standard errors were calculated because our major interest in this study was in characterizing whole-tree responses.

All oak trees on the study property were previously surveyed, identified, and cataloged[4]. All the tree identification numbers mentioned in this study refer to those assigned in the earlier studies.

RESULTS AND DISCUSSION

A brief summary of climatic conditions is presented in table 3. These are provided to assist in interpreting daily courses of plant water relations which are presented later.

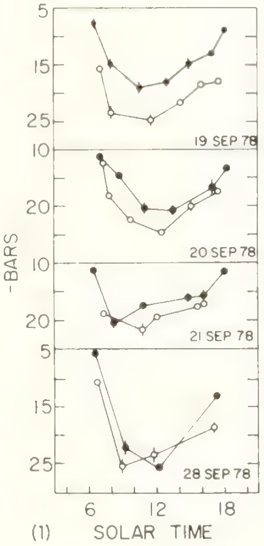
Table 3--Weather characteristics during days of tree water relation measurements. Given are maximum air temperature (T_{max}), maximum vapor pressure deficit of the air (VPD_{max}), average dew point temperature (T_{dew}), average vapor pressure of the air ($\overline{E}$), and soil water potentials at 60 cm depth (Ψ_{60}).

Date	T_{max}	VPD_{max}	T_{dew}	$\overline{E}$	Ψ_{60}
	°C	mb	°C	mb	-bars
19 Sep 78	26.0	29.4	- 5.6	4.02	-
20 Sep 78	27.1	31.8	- 5.5	4.07	-
21 Sep 78	31.2	42.6	- 5.1	4.18	-
28 Sep 78	35.1	44.1	+11.1	13.21	-
30 Sep 78	33.0	40.3	+12.3	14.28	-
04 Oct 78	25.7	16.8	+15.1	17.00	33
11 Oct 78	33.0	43.3	+ 2.7	7.44	-
12 Oct 78	34.9	50.6	+ 7.2	10.14	-
13 Oct 78	36.5	55.2	+ 7.3	10.19	-
24 Oct 78	26.5	20.8	+ 9.5	11.81	21
06 Dec 78	7.9	8.6	- 8.5	3.21	13
09 Feb 79	18.7	14.4	+ 4.0	8.13	[1]

[1] Reading close to zero bars, outside the range of the psychrometer.

Measurements were made in late September to characterize short-term changes in the daily course of pressure potentials in Q. agrifolia subjected to root pruning. Two trees growing on even terrain approximately 120 feet apart were selected. One, Q. agrifolia number 92 (QA-92) had no root system disturbance and served as a control for Q. agrifolia number 94 (QA-94) which underwent root pruning. These data are presented in figure 1. On 19 September 1978, daily courses of xylem pressure potential were measured for both trees prior to root cutting. The root cutting on QA-94 was accomplished between 0840 and 0920 solar time on 20 September 1978. The daily courses for QA-92 were similar on both 19 and 20 September 1978, while QA-94 showed a midday negative shift of about 2 bars following the root cutting. Further measurements showed that QA-94 achieved daily minimum pressure potentials similar to the control QA-92, but had generally high dawn potentials and apparently more rapid afternoon recovery. The major short-term effect, thus, appeared to be the development of more stressful midday potentials, but overnight recovery, as indicated by the dawn potentials, did not appear to be affected.

Similar measurements were made before and following root cutting on Q. lobata tree numbers 18 and 19 (QL-18, QL-19). These data are presented in figure 2. On 28 September 1978, daily courses were measured in QL-18, which served as a short-term control,



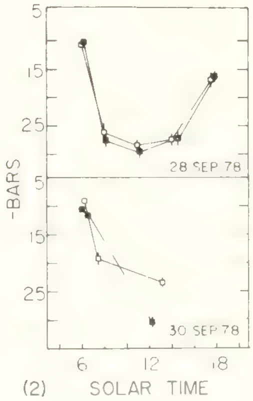


Figure 1--Daily courses of xylem potential with standard errors for QA-92 (○) and QA-94 (●). Vertical bars are standard errors.

Figure 2--Daily courses of xylem potential with standard errors for QL-18 (□) and QL-19 (■).

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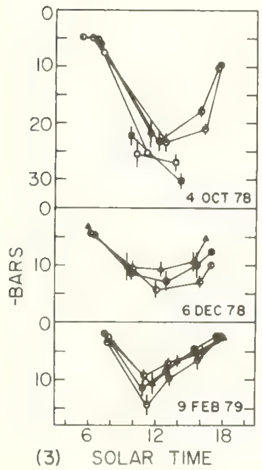
[4] Unpublished reports by James Dean, Lee Newman and Associates, Westlake Village, California.

and QL-19 on the day prior to root pruning. The trees showed similar daily courses in pressure potential, both in the dawn and midday minimum values. Root cutting and trenching were carried out on 29 September 1978, and measurements were again made on 30 September 1978. Again, similar to the earlier data on QA-94, the dawn potentials were similar in QL-18 and QL-19. However, the midday values were notably different, with QL-19 showing midday potentials of around -30 bars, while QL-18 showed values of about -24 bars.

Data in figure 3 are presented to illustrate a broader sample of trees over longer time periods. The daily courses measured on 4 October 1978 show QA-93, QA-94, and QA-89 with similar patterns. QL-18 and QL-19 developed more negative daytime potentials than did the other study trees, probably because of local edaphic conditions at the sandier ridgetop site of QL-18 and QL-19.



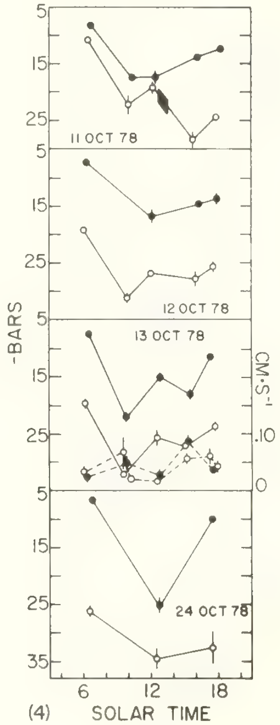


Figure 3--Daily courses of xylem potential with standard errors for QA-89 (◓), QA-92 (○), QA-93 (◐), QA-94 (●), QA-787 (▲), QL-18 (□), and QL-19 (■).

Figure 4--Daily courses of xylem potential with standard errors for QA-92 (○) and QA-94 (●). Also shown are leaf conductances in dashed lines on 13 October 1978. Cross-hatched area on 11 October 1978 indicates the root cutting period on QA-92.

Data presented in figure 3 for 6 December 1978 and 9 February 1979 show daily courses of pressure potentials during the winter wet season when soil moisture is replenished. Daily minimum potentials fell in the -10 to -1 bar range and dawn potentials were in the -2 t -4 bar range. QA-787 is included in these data. This tree was located off the study sit and was used as a permanent control tree which would not be affected by land development operations.

The period of 11-13 October 1978 involved a study of short-term effects of large-scale disruptions to root systems. QA-92, which was scheduled for eventual removal, was selected for experimental root manipulations. In early afternoon on 11 October 1978, a trench was dug 8 to 10 feet deep around approximately 70% of circle formed at a radial distance of two feet from the base of the tree. Morning values of potential in tree QA-92 (figure 4) were 3-4 bars more negative than the other trees, similar to other measurements on this tree on earlier occasions. Root-cutting operations began shortly after 1200 solar time. Measurements at around 1540 revealed that potentials had decreased markedly in tree QA-92, reaching a mean value of -28 bars at a time when QA-94 showed a value of -14 bars. QA-92 then partially recovered in late afternoon to approximately -24 bars at 1750.

The following day, 12 October 1978, the dawn potential measurements of -19 bars showed that tree 92 was unable to completely recover from the previous day's water deficit. QA-94 recovered to a dawn value of about -7 bars. QA-92 exhibited substantially more stressful midday potentials than QA-94, showing a minimu value of -31 bars while QA-94 developed minimu potentials of -17 to -18 bars.

Measurements made on 13 October 1978 agai revealed the same basic difference between the radically root-cut QA-92 and QA-94 which had a much smaller fraction of cut roots. Lack of overnight recovery was again apparent in QA-92 which had a dawn potential of -19 bars, while QA-94 showed values of about -7 bars. Throughout the day tree 92 showed potentials which were substantially more negative than QA-94. Minimum potential was -32 bars in QA-92, and -22 bars in QA-94.

13 October 1978 was a high stress day in terms of air temperature and the evaporative "demand" of the atmosphere (table 3). These environmental conditions brought out a stomatal water stress response pattern which is shown i figure 4, and which is linked to the development of leaf water potentials. The daily course of potential in trees QA-92 and

QA-94 all showed a midmorning minimum, then a partial early afternoon recovery followed by a midafternoon minimum and, finally, a partial late afternoon recovery. These time trends in potential are related to the time course of stomatal conductance. Midmorning conductances were at a relative maximum, promoting higher rates of water loss by transpiration and the subsequent development of decreasing potentials. The midday decrease in stomatal conductance, indicating a partial stomatal closure under water stress, resulted in a partial midday recovery in potential. Stomata re-opened in midafternoon with a consequent decrease in potentials and began closure in late afternoon with a corresponding increase in potentials. This linkage between stomatal activity and potential indicates that Q. agrifolia is able to regulate water use in response to external environmental factors which affect tree water balance and internal factors of water stress which affect a number of processes in plant tissues.

The effects of the root cutting on QA-92 persisted through time as shown on 24 October 1978. It is not known if QA-92 could have survived this water stress regime because it was removed for road construction in late October 1978. The indications are that the root disturbance in QA-92 produced much more damaging and possibly irreversible effects when compared to root disturbance effects measured in the other trees. Thus, there are limits in the magnitude of root system disturbance which the trees can accomodate without major disruption in the tree water system.

CONCLUSIONS

Water relations measurements taken at the study site over the period September 1978 through February 1979 indicate that increased water stress occurred in individuals of Q. agrifolia and Q. lobata which have been subjected to disturbances to the tree water system through root cutting and grading operations. The measurements of water stress, as characterized by xylem pressure potentials, were not of such magnitude as to suggest impending lethal effects; rather, the trees incurred chronic water stresses which would accumulate over time. The potentials of root-pruned trees fell within the range of values reported elsewhere for these oaks (Griffin 1973). It must be stressed that these were carefully managed root pruning and grading operations and the same conclusions may not apply for trees subjected to more routine trenching and grading operations in and near the tree root zone. Drastic root pruning on an experimental tree showed immediate disruptive patterns of pressure potential, establishing that there are clearly limits as to the degree of root damage these oaks can withstand in their present environment.

From these short-term data, it is not yet possible to evaluate long-term effects of such a water stress regime. Plants have evolved a number of mechanisms to compensate for environmental fluctuations in water availability, and this may be particularly true for these Quercus species presumably adapted to the mediterranean summer drought climate pattern. Future measurements will clarify some of the responses of these trees to root system disturbance and fluctuation in water availability, responses which must be understood before adequate oak management programs can be developed.

ACKNOWLEDGEMENTS

We thank Mr. James Dean for the foresight to suggest these studies be undertaken and Mr. Ken Rattner for permitting measurements to be carried out at the study site. Dr. Phil McDonald provided helpful criticism which improved the manuscript.

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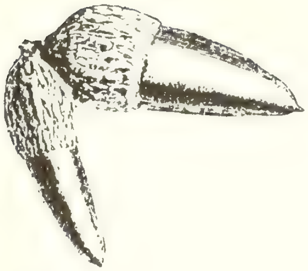

Quercus agrifolia

Oak Tree Banks and Relocation[1]

Richard D. Cross[2]

Abstract: A problem facing both developers and conservationists is how to save valuable oaks in urban developments when they are in a road right-of-way or future building space. Our unique solution is that if a tree is in good condition, it can be dug up and moved. Instead of boxing a tree we trench around it, dig it up, and move it to another location. In this way, many trees can be moved each day. Another facet of this operation is the temporary storage of trees in what we term "tree banks" for up to 3 years duration. The trees are laid in trenches and partially covered with soil. One-time relocation has been successful 85 to 95 percent of the time.

There is a tremendous amount of encroachment and urbanization that has a significant effect on oak trees. Much of it is detrimental. What we have proposed in the last four years is that many trees do not have to be cut down if a road is going through. You can relocate the tree. It can be removed and taken -- stored in the ground. If a roadway is going through it's mainly a decision whether or not the tree should stay or go. Should we preserve the tree by putting a costly well around it, or should we take the tree out? Now, if the tree is in the middle of the roadway, or a condominium is going to be put in, in most cases the tree is taken out. It's expensive to redesign around trees. And in many cases if you redesign around the tree, there are serious consequences that you have to deal with later which involve more expense.

All too often in Southern California we find a particular site where they're going to cut down a slope and fill a valley, so they not only have to cut out the trees that are on the top, but they have to fill in and actually remove the trees on the bottom.

The ideal thing is to have the tree in the landscaping. In fact, you can remove the tree and relocate it back in again after you have built that particular project. Say, building a condominium or a roadway, or what have you. Trees can be moved -- small trees, large trees. Now, I should say oaks have been moved before, using a boxing technique. The problem with this is that boxing is very expensive and time consuming. When the developer gets that grading permit, he has a loan out from the bank and he wants to start grading. He can't wait around for two or three months, six months, up to a year boxing trees. He has to move right away because time is money. He wants to get the homes built and sold. So the developer needs to move in quickly. The best way to do this is burying the tree or digging the tree out with a bulldozer, not boxing it. This may sound radical, but it can be done. We'll be working in conjunction with the City of Los Angeles on a pilot project. We'll be taking some trees out that are about 65 feet high with about a 70-foot spread. We will move eight or ten of those in twelve hours

The ideal way is to move the tree in one day, if you can. We have moved up to 12-inch diameter trees. We have moved up to eighteen trees in a single day.

In some cases we store the trees for as long as a year. They'll build the pads, start putting up the frames on the house, then the trees can be taken out of the storage area.

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[1] Presented at the Symposium on Ecology, Management and Utilization of California Oaks, June 26-28, 1979, Claremont, California.

[2] Horticulture Evaluation and Research Systems, Encino, California.

When they're laid we'll dig a ditch 8, 10, 12 feet deep, and lay the tree in, and then fill in as much soil as possible on the tree.

Now, with pads that developers put up, the soil is compacted; so you can't leave a tree in its original position in many cases because they have to compact to 90 percent. They have to dry the soil down hard so the structure will stand over the years. And this is a very severe trauma for your oak tree. That's why many of them in urban situations will succumb even if you're building around them.

So if you've got the room, you store your trees, and you move them later; and you can also take your oak trees and put them in more advantageous positions. An oak tree in front of a home is worth a great deal more money than it is in the back.

If you're going to move an oak tree in this fashion, there are certain things you have to take into consideration. One of them is, select a proper site. You have to be very careful that you don't run into a situation where a hole was dug to receive the tree, and underground water filled the hole. Just imagine what would happen if the tree was put in there! So site selection is very important.

Trees that are not weakened, and are free from pests and fungus can be moved. Insects such as the western sycamore borer (Ramosia resplendens) often hit trees weakened by drought. Check for these. You don't want to move a tree that is severely hit or in a state of decline.

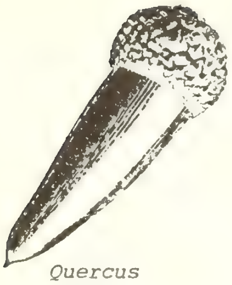
The Pacific flatheaded borer (Chrysobothris mali) is a potential pest both before and after moving a tree. If you're going to relocate or store trees, you first have to diagnose the trees' condition. Many trees are moved that shouldn't be, even boxed trees. If they're moved and not taken care of properly, a flight of borers will move in and take out the trees. This is probably the major pest attacking relocated oak trees.

Also check for wind damage. You should prune the damaged branches because in many cases you will put the tree near a building or near a place where a building will be erected. You don't want to be liable for damage to the building.

What we're trying to say is there are other alternatives. It's not a case of a tree has to go, or does it stay, and what do we do to preserve it? You can now take trees out. We feel that before you cut the tree down, you can relocate it. If you can't relocate it, store it for a year, two years, three years. Then take the tree out and put it back where you want it. You can do this, and I think that the landscapers, in the upcoming years will be able to use the environment we have, rather than bringing in trees that decline, that are not indigenous to this area, trees such as eucalyptus that create a problem of maintenance, pest problems and such. This is a new approach, but it's going to find favor with a lot of landscape architects.

In storing, we lay trees down at an angle depending on the type of tree. If the tree with multiple branches has a big spread, you really can't lay it down; but trees that come off hillsides and dense growth grow straighter, so you can lay them down. We tried it to conserve as much space as possible. In the Calabasas area we stored 90 or 95 trees.

We can move the trees in the summertime or the wintertime. We prefer -- I know this sounds radical -- but we prefer to move the trees in the summer rather than the winter. If you've ever had a D-9 "Cat", a large piece of machinery, if you get into soft soil, wet soil, she'll go right to the belly pan, and you're stuck there with the machine. But we have found that in summertime it's ideal. We don't worry about the heat problem. I worry more about my machinery getting in and out.



Quercus lobata

Characteristics of Root Systems: California Oaks[1]

W. D. Thomas[2]

Abstract: Intensive examination of root systems for 21 oaks (Quercus lobata and Q. agrifolia), during excavation in a development project in the Conejo Valley (Ventura County, California), indicated that the major root zones were within 5 to 8 feet from the stem. Buttress roots within that distance send down sinker roots as far as 30 ft. with lateral feeder roots emanating at interfaces between different soil types in the soil profile. Shallow lateral roots with feeder roots only at the tips may extend as far as 90 ft. from the stem; these are assumed to be winter feeder roots. Tap roots on all trees, regardless of species, were degenerate and non-functional. Most roots had infections by Dothiorella querci and/or Phytophthora cinnamomi, many of which had been compartmentalized. Excision of up to 45% of entire root systems have met with no deleterious effects over six months; all roots were coated with Tree-Heal and wrapped with plastic until the excavations were backfilled.

This study was part of a research program at Thousand Oaks. North Ranch and Westlake Village comprise a very expensive development sponsored by my friend, Johnson Holmes. The project is still not completed. It will be two or three months before we can wrap up all our data.

This has been one of the projects that tree men dream of because it gave us the rare opportunity to study the characteristics of the oak roots. I entitle my talk "California Oaks" because the eastern oaks have somewhat different characteristics. We are talking about trees that are adapted to long drought periods and then lengthy stretches of wet weather, soaking rains, washing and so forth.

Hence we see different characteristics than those which appear in either the eastern or southern oaks. But for the contractors and developers who are concerned with this problem, the study is extremely valuable.

Most of the impacted oaks are on an area that has been rather highly grazed. Trees are scattered rather than occurring in large groups. In our study area we found 21 trees impacted by construction. At the time we did not know it was possible to lift trees, bury them for a time, and then replace them.

We selected one of the oaks which was lost to construction activity. This became our study tree and we tore it completely apart. We dug it out and manicured the roots so we could study them. We had to give our help two or three lectures about roots so as to maintain a high level of interest on their part.

Now this tree appeared to be a very solid one. It was one of the most beautiful on the construction site. But as we dug around it we found it became weak from a loss of roots, and split at the crotch. Inside we found a core of carbon. Apparently the tree had grown around the parent which had been damaged by fire a long time ago. The core was solid carbon and we detected no decay in this area. Underneath the core, however, we found decay where the fire had not hit.

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[1] Presented at the Symposium on Ecology, Management, and Utilization of California Oaks, June 26-28, 1979, Claremont, California.

[2] Forest-Ag, Lafayette, California

One of the characteristics of these California oaks is a degenerate tap root. It appears to be active in the young oaks but then for some reason which is not clear to us, it degenerates as the tree matures. It is unusual to find old oaks with a solid tap root. As we cut through we find that most of the roots occur within the two-to-three-foot zone. As we penetrate below two to three feet the secondary roots are rarely found.

We find that if we are going to encounter mycorrhizal activity it will occur within the first foot or two of the stem. Farther out we find a paucity of mycorrhiza. The litter and everything that collects under the tree favors the development of fungi.

Now one of the most striking observations we make is the development of sinker roots. These sinkers will come as laterals, going down from the secondary or buttress roots somewhere within five feet, or closer, to the stem. Seldom do we encounter sinker roots beyond five feet. But we could expect anywhere from three to ten sinker roots around a tree, within three to four feet of the stem. Apparently these are the roots which provide the survival mechanism for these trees during the dry seasons.

Looking at the map of the root zone of this particular tree it is evident that the laterals which were found went clear out to 60 feet. If we look at the root zone of the profile, we find that on one side we see nothing beyond six feet from the stem. Coming around on the south side of the tree we had a group of laterals coming down to three feet, but we had a great big, over-two-inch lateral, down in the three-to-four-foot zone. Others are less than two inches in size. Moving around the tree we find a little cluster of laterals probably coming from one major group. Going around on the other side of the tree we find laterals out past the 50 foot marker as well as a small cluster right around the stem and another great big lateral down at the four foot zone.

This was the basic root structure of this particular tree which we sacrificed.

Now during the process of our examination all of the roots were hand-dug and cut, were wrapped with plastic and painted with tree-heal. There's some question in my mind about the value of this procedure. I think we probably could have sprayed the roots with paraffin just as well, because we found that whatever the situation was, some drying the cut roots showed drying for about two inches up from the cut. Others dried for three or four inches. But be that as it may, the callus had formed around this area, almost immediately upon cutting. It is almost impossible to get there and treat that root before it callused to set up its own protective mechanism.

Other surprising things we found were these snake-like winter feeder roots. One particular feeder was rather neat. It lay about six or eight inches beneath the surface, running out as far as 90 feet. Except right at the tip, there were no feeder roots on it. The small tip feeder roots looked much like the tail of a poodle dog.

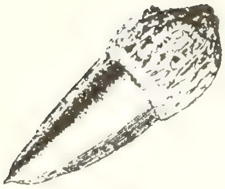
Along the roots we found quite a bit of infection. We isolated Dothiorella querci and Phytophthora cinnamomi. In many cases the roots had compartmentalized around these infections and the tree had gone on to add additional roots. The natural mechanism the trees have for withstanding many of these infections is just amazing. In fact we also found Streptomycytes that were working on some roots and an abundance of Trichoderma.

On one root about 60 feet from the trunk we found Dothiorella and Fusarium and clear out here the tree had compartmentalized around it.

As far as the depth is concerned, it's fascinating because we found that at every layer of the soil zones we would see mats of feeder roots. Then the root would go on down and there would be another cluster of feeders. There was a beautiful layering of feeder roots in each transitional zone in the soil profile. This continued to a depth of 30 feet. So these are the areas from which the tree is obtaining its sustenance.

In the case of one particular tree where a wall was to be built, we cut out about 45% of the root system and several people were of the opinion that it would die. We did the cutting during the August dormancy. The tree, however, had large roots, three feet deep, extending out as far as 80 to 90 feet in the direction opposite the wall. The root system which was left did the job. Next spring the tree leaved out before the others did and it came out beautifully.

So much depends on the kind of care we give these oaks, and the protection they receive. On the last check 11 months after cutting, we have yet to lose a tree on this development. We have not seen a tree really wilt if we are giving it proper water. So you see it is possible to come out with beautiful trees in a well-developed program.



Quercus agrifolia

California Oaks and Outdoor Recreation[1]

Sam S. Alfano
Recreation Management Officer
Los Padres National Forest
Goleta, California

Abstract: California oaks have played an important part in western Indian culture as well as the colonization of the State by the Spanish. The desires of farmers, ranchers, subdividers and other land users have caused a decline in the oak stands throughout the State. Some of the most desirable recreation sites located in California are located in oak groves. These oaks not only provide shade and shelter but also are the habitats of many wildlife species that provide visual enjoyment to the outdoor recreationist. It is essential that we retain, wherever possible, the remaining stands of oak, not only in our recreation sites throughout the State, but also in and adjacent to our growing communities. It is also essential that we pursue silvicultural practices that will assure growth of young trees in our old growth stands throughout the State.

It was Washington Irving who said, "He who plants an oak looks forward to future ages and plants for posterity. Nothing can be less selfish than this."

If Gallup took a poll of the most scenic and picturesque native trees of California, there is no doubt in my mind that California oaks would head the list.

There is no question that oak species had a special significance in early European culture. English oak, for example, provided fuel, timber for ship building, wood for housing and forests which generated such tales of hope, freedom and adventure as the legend of Robin Hood. Strong, tough and robust, the oak was a symbol of manhood.

The California oaks were just as significant to Indian culture. Although acorns provided a major footstuff for many Indian tribes, it can be assumed that they also attached special aesthetic and perhaps spiritual values to these bountiful trees. One can imagine the joy and excitement that took place as the women and children found their way along ancient trails to the oak groves. There was, no doubt, a feeling of pleasure and exhilaration to be in and among these ample providers of food, who modified the heat of summer, winds of fall, coldness of winter and the rains of spring.

The oaks played an integral part in the Spanish culture, for the early Mission trail from San Diego to Monterey wound among the forests of oak. Beneath the outstretched limbs of a coast live oak, Padre Junipero Serra in 1770, planted his cross and celebrated the first mass conducted on the Monterey Peninsula. The Spanish explorers interpreted the coast live oak as an indicator of fertile land and evidence of suitable location for residences. American pioneers did so as well. And even today, in this time of stress and pressure, just walking down a leaf-covered lane brings serenity and peace of mind.

Fifteen of America's 68 species of oak grow in California. If one examines a distribution map of the common species of California oaks, it is evident that they are adaptable to a wide range of elevations, soils and climates.

There is no estimate of the acreage occupied by oaks before the white man arrived in California. There is an estimate by some experts, however, that originally 800,000 acres of riparian habitat occupied by oaks existed in California and has now been reduced to some 12,000 acres. In the Coast Ranges and Sierra Nevada foothills, ranchers burn, spray and bulldoze blue oaks to turn woodlands into grasslands under the questionable assumption that fewer oaks will mean more grass for cattle. The continuing reduction of oak stands throughout California further emphasizes the need to retain the remaining acreage for outdoor recreation purposes.

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[1] Presented at the Symposium on Ecology, Management and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

Another point about conversion concerns water. A number of people today want to see the deciduous oak forests cut down and replaced with conifers. They are forgetting one of the big costs of conversion--the cost of water lost by switching from deciduous hardwoods to conifers. Conifers intercept rain and snow in their crowns and much of it is lost by evaporation. Deciduous hardwoods, on the other hand, allow the precipitation to fall through the crowns to the ground. Here the evaporative forces are much less. In a study in the southeast, annual streamflow, which is water available for reservoir storage, decreased by 20% fifteen years after the area was converted from a mature deciduous hardwood forest to white pine (Swank and Douglass 1974). This loss will continue and probably worsen as the pines grow larger and drink more water. Other studies in the southeast and north central states have shown similar results.

Because water recreation is an inherent part of outdoor recreation, and because I think Californians are going to need all the water they can get, this concerns me.

Adaptability to a harsh and variable environment makes these species extremely important to the outdoor recreationist. The valley oaks located on deep soils in the interior valleys are observed by the passing motorist as eye-catching silhouettes which break up the monotony of the landscape. The California black oak, which is found in a wide range of elevations throughout the State, is known for its scenic beauty throughout the year and especially when the species puts on its colorful fall display.

The coast live oaks are generally found along our valleys and water courses throughout the State. These are mostly evergreen species and provide continuous shade and shelter to outdoor visitors. It is not by chance that many of the campgrounds, parks and picnic sites throughout southern California and other parts of the State, are located in oak groves.

California black oak in southern California campgrounds and picnic areas is likely to increase in the future. A virulent fungus (fomes annosus) attacks the roots of local conifers and kills them in patches up to four or five acres in size. New seedlings contract the disease and soon perish as well. Seedlings of California black oak seem relatively immune to this pathogen and, consequently, are being used to replace the conifers. Likewise, photochemical smog is killing conifers while California black oak is little damaged. The ability to shed smog-laden leaves in the fall is one big advantage of being deciduous.

The need for quickly establishing vigorous young black oak seedlings has stimulated research in growing and outplanting this and other oak species. Nearly 100 acres on Liebre Mountain in the Angeles National Forest will be set aside for tests aimed at developing planting stock and outplanting methodology for successful establishment of these oak species.

The attractiveness of oak groves to the outoor recreationist and to the recreation planner is understandable. Yet the desirability of these locations presents a relatively minor but nevertheless certain amount of risk to the user. The landscape architect is careful to avoid the unnecessary removal of trees when he designs a recreation facility. He avoids road locations that may necessitate the removal of large limbs and cut root systems. With all his carefulness, however, the problem of tree (including oak) failure in campgrounds, parks and picnic sites has concerned many agencies throughout the State.

In 1968 a California live oak fell across a tent located in the Cerro Alto Campground within the Los Padres National Forest. Fortunately, no one was killed but an elderly woman had to be hospitalized for nearly eight months.

On a quiet spring day, what appeared to be a sound canyon live oak fell with a crash into a campground unit within the Wheeler Gorge Campground. A young boy received minor injuries and some $600 worth of damage was done to a recreation vehicle.

An Easter Sunday almost turned into a day of tragedy as the heavy limb of a canyon live oak within Tuckers Grove County Park collapsed onto picnickers. Three persons were treated at Goleta Valley Hospital for minor injuries. In spite of these near misses, millions of visitor days have been spent in southern California campgrounds without injury.

Questions on oak soundness often are raised by park rangers and campground attendants. Annual inspections of sites to note dead limbs and canker growth are essential. Examination of core samples obtained from an increment borer can provide signs of heart rot in the trees. Both are being done in Forest Service campgrounds.

The best information on tree failures in recreation areas has been compiled by Dr. Lee A. Paine and his associates located at the Pacific Southwest Forest and Range Experiment Station at Berkeley, California. Dr. Paine's publications entitled, "Tree Failure and Accidents in Recreation Areas: A Guide to Data Management for Hazard Control," "Accident Hazard Evaluation and Control Decisions on Forested Recreation Sites," and "Administrative Goals and Safety Standards for Hazard Control on Forested Recreation Sites" constitute an extremely good basis for evaluation of oak hazard problems.

This national computerized program provides for five classes of failure: upper bole, lower bole, butt, limb and root system. A query to the computer will show how many failures injured people or damaged property and what costs are involved. Failures can be related to species of oak, defects contributing to the failure, triggering environmental factors, tree diameter, tree age, elevation of the site, time of day and the year in which the failure occurred. Currently Los Padres National Forest personnel are conducting annual reviews of recreation sites to assess the hazardous tree situation.

In our zeal to remove seemingly hazardous trees, however, it has become necessary to use a certain amount of good judgment. An apparently hollow oak may be the home of a spotted owl, the refuge of the California grey squirrel, the nesting place of the Steller jay or a perch for a sparrow hawk. In California alone, more than 45 wildlife species consume acorns, including woodpeckers, band-tailed pigeons, Steller jays, raccoons and ground squirrels. Acorn mast also constitutes a significant percentage of the diet of many birds and mammals. It is this interrelationship of wildlife to oak stands that draws the outdoor visitor to see and hear the many wildlife species that abound within these ecosystems. This interrelationship appears to have been recognized by forest managers who manage the thousands of acres of California black oak in the higher elevations throughout the State.

The importance of oaks in the valleys, foothills and forests has not drawn the attention that is needed. It is imperative that outdoor recreation managers begin to regenerate the valley and live oak species by pooling the latest information on oak silviculture.

Recently a 10-acre site was planted to canyon live oak seedlings on the Santa Barbara District on the Los Padres Forest. Stock in five-gallon containers was outplanted using the latest techniques. Although the seedlings were well cared for during the hot dry summer months, the roots provided succulent dinners for hundreds of ground squirrels in the area.

To avoid this problem,the roots of oak seedlings planted in the Sage Hill Campground located across the river were covered with a 1-inch wire mesh. Hopefully, this technique will allow the root systems to take hold before being eaten by ground squirrels.

The successes and failures regarding oak regeneration need to be shared by all concerned, so that the least amount of time, effort, and money is lost, and so that we can again re-establish thrifty stands of oak throughout the valleys and foothills in this State.

We should not overlook the outstanding aesthetic value provided by such oaks. Vast acreage throughout the valleys and foothills have been grazed by cattle to the extent that young oak seedlings are nonexistent. Who is responsible for maintaining these last vestiges of what was once an ocean of green? The aesthetic appreciation of oaks as a form of outdoor recreation is evident by the care given to featured trees in urban areas. Unfortunately, too many oaks are eliminated for subdivisions, shopping centers and other asphalt and concrete facilities. The quality of the urban environment could be enhanced so much more if only oaks, and plenty of them, were to grace the streets and buildings.

The sensitivity of the Indians for oaks is found in a statement made by Sitting Bull. He proclaimed, "I wish all to know that I do not propose to sell any part of my country, nor will I have the whites cutting our timber along the river, more especially the oak. I love to look at them because they endure the wintry storms and summer heat, and not unlike ourselves, seem to flourish by them." Let us heed Sitting Bull's proclamation so that future generations can see the magnificence of our native California oaks and recreate under their spreading branches.

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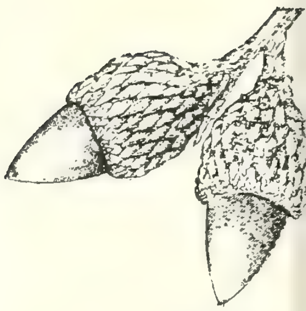
Damage Factors



Quercus wislizenii

Insects Feeding on California Oak Trees[1]

Leland R. Brown[2]

Abstract: The typical damage and the distinguishing characteristics of the injurious stage are described and illustrated for the following 11 important and/or common insects feeding on California oak trees, categorized as: Sucking insects: oak pit scales, crown whitefly; Leaf-consuming insects: California oak moth, tent caterpillars, fruittree leafroller; Boring insects: western sycamore borer, oak twig girdler; Acorn insects: filbertworm, filbert weevil; and Gall insects: two-horned oak gall, distorted leaf gall. The management of these categories of injurious insects is discussed, emphasizing the philosophy and decision-making process.

INTRODUCTION

Insects are one of the important categories of "damage factors" affecting oaks. In California well over 125 insect species have been recorded feeding on various parts of oak trees. Approximately 15 of these insects are of major importance to oaks; a few of these important insects are discussed here.

For the person managing oaks it is logical to categorize insect pests by the part of the oak they feed on. This subdivides the large number of oak insects into groups of less formidable size, and in large part these groups are natural in that sucking pests are together, chewing larvae of moths and beetles are grouped, etc. Furthermore, control measures are frequently the same for insects feeding the same way on the same plant part. Thus the sequence of insects discussed here is as follows: sucking insects; leaf-consuming insects; boring insects on trunks, limbs, and twigs; boring insects in acorns; and gall insects.

What the oak manager will do about insects feeding on this tree may depend on where it is. The infested tree on an urban homelot may require an immediate spraying of insecticide, whereas such an oak in a wild, forested area may require observation and the encouragement of natural predators and parasites. The final part of this paper will discuss what man can do to regulate populations of these injurious insects.

For a more detailed account of California oak insects and their management, the reader may wish to write the author for a copy of Brown and Eads (1965). Most species mentioned here are well covered by Furniss and Carolin (1977) which is available to most foresters.

SUCKING INSECTS

Sucking insects include whiteflies, aphids, leafhoppers, tree-hoppers, and scale insects. The long, stylet-like mouthparts of these insects are inserted into or near the vascular system of the oak, generally the phloem, and the watery, sugar-containing sap is withdrawn, sometimes in quantities that kill leaves and twigs. The plant cell structure is left intact. Often these sucking insects inject into the plant some of their saliva which may be toxic enough to kill tissue or cause it to be deformed. Sucking insects seemingly have few defenses, except their generally enormous reproductive powers. Honeydew may be dropped from infestations of some sucking insects, such as aphids and certain scales. Only two sucking insects are discussed in detail here: oak pit scales, because of their great potential for harm, and crown whitefly, because it is so common.

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Oak pit scales

If the twigs and smaller branches of an oak are leafless, and weakened or dead, like those in figure 1, a close search should be made of the twig surfaces. If many shiny, round, convex, yellowish-green, pin head-sized bodies are found in dimpled areas of the bark, as in figure 2, then most likely one of the oak pit scales, (Asterolecanium species, Homoptera: Asterolecaniidae) is present. The dimples or pits are especially noticeable when the scale is removed. When the young crawler scale first settles, the bark may be smooth, but with the insertion of the mouthparts and injection of its toxic saliva, the bark around the scale begins to swell so that the mature, attached scale appears to be residing in a pit. Three Asterolecanium species are present in California: A. minus, A. quercicola, and A. variolosum with A. minus being the most common. Insofar as known they have a single generation annually with peak hatch in late May. Of all the sucking insects affecting the oak tree, the pit scales can do the most harm because they frequently escape early detection, have a high reproductive potential, and have toxic salivary secretions. Pit scale infestations can be devastating, particularly in addition to droughts.

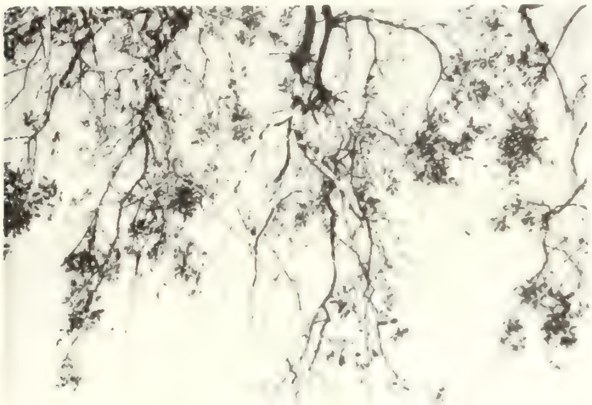
Figure 1--Note generally weakened condition of these branches of valley oak from a severe infestation of an oak pit scale, Asterolecanium minus.

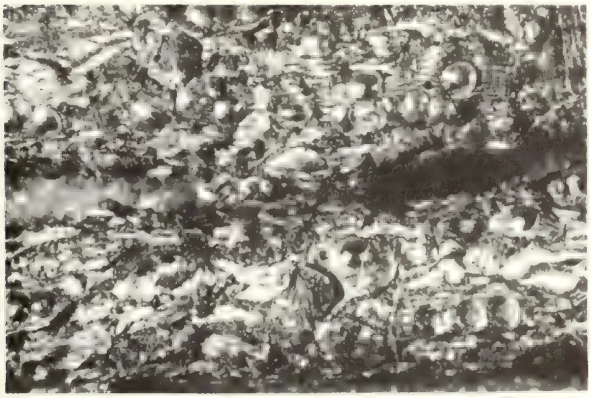
Figure 2--Numerous adults and pits of the golden oak scale, Asterolecanium variolosum, on two twigs of Quercus robur. 1.7X.

Crown whitefly

One of the most common sucking insects, especially on black oaks, is the crown whitefly, (Aleuroplatus coronatus, Homoptera: Aleyrodidae). Superficially it appears like a salt and pepper encrustation on the bottom side of the leaves; but when magnified, as in figure 3, each immature whitefly appears to be a flat, scale-like, black body from which issue several large plates of white wax, somewhat in the form of a crown. The adults appear more like a conventional insect in being winged and free of the leaf. The tiny adults are especially noticeable around oak stands in the spring of the year when they fly in such numbers as to resemble the swirling flakes of a snow storm. At such times this whitefly is a nuisance pest. But at other times when the immature forms encrust the leaf in high numbers it is not obvious what the damage is to the leaf or tree.

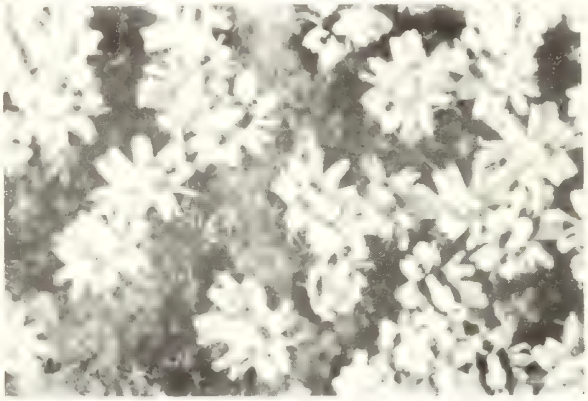
Figure 3--Immature forms of the crown whitefly, Aleuroplatus coronatus, on the lower leaf surface of coast live oak. 8.6X.

Other sucking pests of oaks

Oak treehoppers (Homoptera: Membracidae)
Gelatinous whitefly (Aleuroplatus gelatinosus, Homoptera: Aleyrodidae)
Stanford's whitefly (Tetraleurodes stanfordi, Homoptera: Aleyrodidae)
Woolly oak aphid (Stegophylla quercicola, Homoptera: Aphididae)
Black-punctured kermes (Kermes nigropunctatus, Homoptera: Kermidae)
Oak wax scale (Cerococcus quercus, Homoptera: Asterolecaniidae)
Ehrhorn's oak scale (Mycetococcus ehrhorni, Homoptera: Asterolecaniidae)
Oak lecanium scale (Lecanium quercitronis, Homoptera: Coccidae)
Oak scale (Quernaspis quercus, Homoptera: Diaspididae)
Coast live oak erineum mite (Aceria mackiei, Acarina: Eriophyidae)

LEAF-CONSUMING INSECTS

This category of insects is readily noticed because the forms themselves are relatively conspicuous as is the type of damage they do. Also, their defecated droppings may be in such quantities as to appear in windrows on the ground and sound like a light falling rain. These insects eat the cell walls and watery cell contents of the leaves. The loss of leaf tissue reduces the food-making capability and slows the growth of the oak. All of the leaf blade may be consumed, leaving only the ribs, or only one leaf surface, usually the lower, may be removed in spots. This is referred to as "skeletonizing." Also there are a number of insects on oak leaves that may spend a part, or all, of their immature stage mining between the upper and lower leaf epidermis. Larvae of moths are the most common oak leaf consumers, although there may be stages of beetles or wasps that attack the leaves. Three of the most common and important leaf consumers are discussed here: California oak moth, tent caterpillars, and fruittree leafroller.

California oak moth

This voracious defoliator, also called the California oak worm, is perhaps the most important insect pest of oak trees during years of normal rainfall. During drought years the oak twig girdler probably equals it in importance. But it is typical of oak moth infestations to exist in extremely high populations during one year; then these populations will collapse and any stage of the insect will be difficult to find for 4 or 5 years. These population collapses may result from a depletion of oak leaf food and/or a variety of insect parasites and predators (Harville, 1955) that build up during an oak moth epidemic. They are also subject to a naturally occurring wilt disease. The California oak moth (Phryganidia californica, Lepidoptera: Dioptidae) is also curious in that it is the only member of its family in the United States. Most of the dioptids are tropical, but this one ranges into California, to north of San Francisco, and into Arizona.

The larva (fig. 4) when full-grown, is about 25 mm long, without noticeable hairs, and it has a large, brown head. The body is mostly black but may have longitudinal stripes of white, red, and yellow. Although each larva is relatively slow-moving, it

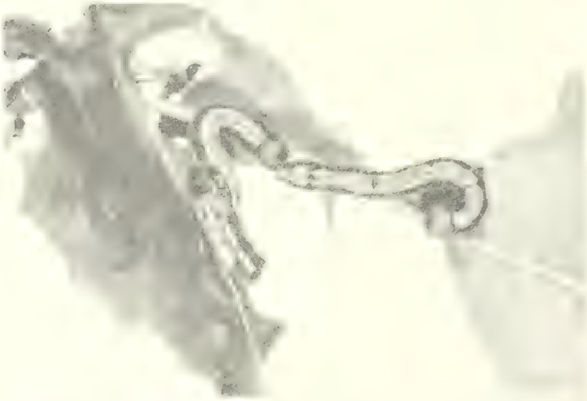

Figure 4--Fourth-instar larvae of the California oak moth, Phryganidia californica, on injured leaves of coast live oak. 0.9X.

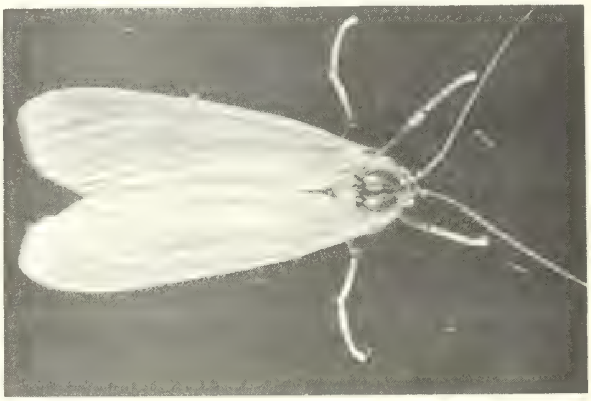

Figure 5--Adult female of the California oak moth, Phryganidia californica; note thread-like antennae. 1.7X.

consumes a great amount of oak foliage. The adult female (fig. 5) is uniformly cream-tan except where the black cuticle is hairless on the back of the thorax. The female has thread-like antennae whereas the male's is feather-like; he also has a faint yellow spot in the center of each forewing. In most of California there are two annual generations of oak moth, but there may be as many as three in southern California. Usually larvae will be present and feeding from mid-March to mid-May and again from mid-July to mid-September.

Tent caterpillars

There are at least two tent caterpillars of the genus Malacosoma (Lepidoptera: Lasiocampidae) that may occasionally seriously defoliate oaks; included are M. californicum, the western tent caterpillar, and M. constrictum, the Pacific tent caterpillar, see figure 6. Tent caterpillars are so-called because some of them spin great quantities of silk which they arrange in the crotches of twigs. They congregate on these tents to rest at certain times of the day. Although the species mentioned here will spin and lay down a silk line as they wander about the tree, they seldom if ever will form this silk into a tent. These mostly blackish caterpillars are fairly large, being over 35 mm long when full grown. They are quite hairy with tufts sticking out their sides. These hairs are grayish or cream-colored, whereas some of the hair clumps protruding from the top are orangish. Most of these tent caterpillars have a fair amount of speckled, light blue on their sides. The Pacific tent caterpillar has a dark blue head (fig. 6). There is a single, annual generation with larvae active from early to late spring.

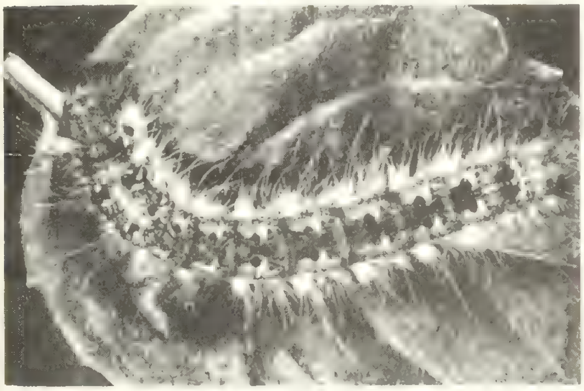
Figure 6--Mature Pacific tent caterpillar, Malacosoma constrictum. 1.3X.

Fruittree leafroller

Archips argyrospilus (Lepidoptera: Tortricidae) is called "fruittree leafroller" since it is one of the most common and important pests of commercial fruits, especially pome fruit, but it has a wide host range and defoliates many woody ornamental plants. For at least 30 years it has defoliated, with some regularity, the California black oak in the San Bernardino Mountains. In common with other members of this moth family the larvae tie the leaves together with silk in a kind of "nest" (fig. 7) and feed on these leaves.

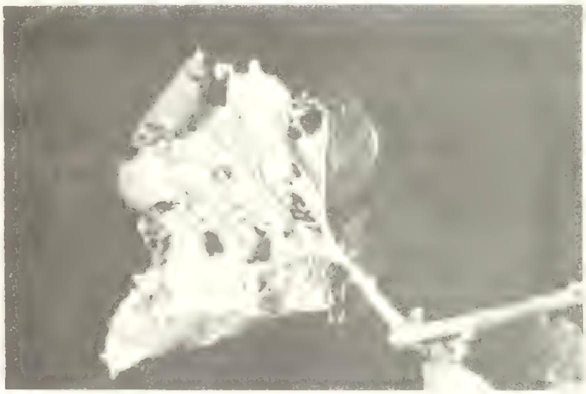
Figure 7--Larval injury and leafrolling of the fruittree leafroller, Archips argyrospilus, to terminal leaves of coast live oak. 0.5X.

As the larvae (fig. 8) become larger they tend to feed exposed, especially on the younger leaves. If disturbed they will usually spin a thread and hang tail downward. They wriggle violently at the least disturbance. The 20 to 25 mm long larval body is

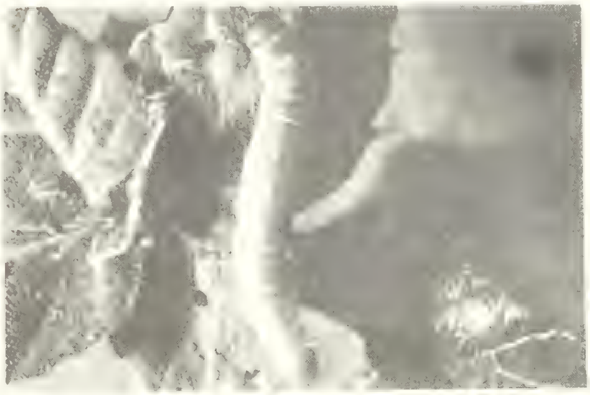
Figure 8--Mature larva of the fruittree leafroller, Archips argyrospilus, on leaves of coast live oak. 2.1X.

essentially free of hairs and is a light pastel green, with the head a light, shiny brown. Populations of this leafroller can become enormous and cause the complete defoliation of Quercus kelloggii. It is curious that Q. chrysolepis is hardly fed upon in contrast to other local Quercus species. Evidently there are few effective natural parasites and predators. The larvae are most active from late March into May; this may be later in the high elevations.

Other leaf-consuming insects

Live oak leaf cutter (Vespina quercivora, Lepidoptera: Incurvariidae)
Oak ribbed case maker (Bucculatrix albertiella, Lepidoptera: Lyonetiidae)
Oak leaf blotch miner (Lithocolletis agrifoliella, Lepidoptera: Gracilariidae)
Stenomid oak leaf tier (Setiostoma fernaldella, Lepidoptera: Stenomidae)
Phycitid oak leaf tier (Rhodophaea caliginella, Lepidoptera: Pyralidae)
Western tussock moth (Hemerocampa vetusta, Lepidoptera: Liparidae)
Salt-marsh caterpillar (Estigmene acrea, Lepidoptera: Arctiidae)
Black oak woollybear (Hemihyalea edwardsii, Lepidoptera: Arctiidae)
Live oak weevil (Deporaus glastinus, Coleoptera: Curculionidae)
Oak leaf sawfly (Periclista species, Hymenoptera: Tenthredinidae)

BORING INSECTS

Insects in this category bore or tunnel through any tissue of the oak except the leaves and acorns. The tissue cells and the watery cells and the watery cell contents are chewed with hard mandibles, ingested by the insect, and passed through its digestive tract. These undigested parts are eventually defecated as fecal pellets or frass. This sand- or powder-like frass is loosely or tightly packed in the burrow behind the insect, where with some insects it remains, but with others an opening is made and the frass is eventually pushed to the outside. An example of an insect employing both means of frass disposal in its life cycle is the bark beetle or scolytid: the larvae pack the frass in the burrow, whereas the adults push the frass to the outside. Because the boring insect is hidden, it is not until the appearance of frass on the outside, or the decline or death of tissue beyond the burrow, that it is discovered the oak is infested. Thus, considerable damage may occur before we become aware of it.

Damage from boring insects can be the most devastating type of insect damage. If it is beneath the bark in the cambium tissue, usually the xylem and phloem tubes are cut, having a catastrophic effect on the tissue supplied by these vascular tubes. And, a relatively small area of bored trunk can have an effect on a relatively large area of limbs, twigs and leaves. If the boring is in the wood, or non-living part of the tree, the immediate effect is less devastating; but the long-term effect may be a weakening of that structure, even to the point of its falling to the ground.

Another consequence of the insect's being buried in the tissue is that there is almost always no way it can be reached; eventually it, or usually a later life cycle stage, will come out of the tree and then it can be treated with an insecticde or other control measure. This means that when dealing with boring insects, we must have a good knowledge of its biology or life cycle development. But even with the most precise knowledge, variations in the rate of development of individuals of a boring insect population, together with vagaries of the ambient temperature and its effects on this development, make the control of this insect category the most difficult of all. A complicating factor with most boring insects (buprestids, cerambycids, scolytids, as examples) is the attractiveness of water-stressed trees. Often times supplying the tree with water is the most important insect control measure.

Western sycamore borer

Although this clear-winged moth (Synanthedon resplendens, Lepidoptera: Sesiidae), is well-known as a sycamore pest, it is also very common and important on oaks. On either of these trees a swelling, roughening, and darkening of the bark or tunneling on the trunk, larger limbs, or limb crotches is the characteristic and readily visible damage. There is frequently an abundance of reddish-brown, sand-like frass in the crotches or on the ground surrounding the trunk. Sometimes the thin, paper-like pupal cases may be seen protruding from the bark, indicating that the adults have emerged. If the roughened bark is smoothed with a rasp or draw knife (fig. 9), the numerous, meandering tunnels of the larvae will be exposed.

Generally only the less vigorously growing bark is affected. On an oak used for ornament this damage is unsightly, but it is questionable how serious this damage is physiologically. The affected tissue is

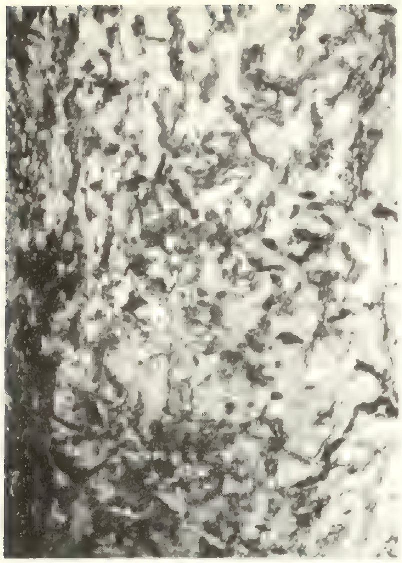

Figure 9--Trunk bark of sycamore scraped to expose numerous meandering tunnels of the larvae of the western sycamore borer, *Synanthedon resplendens*; oak bark so scraped is similar. 0.17X.

primarily bark, although tunneling into the cambium region is common, where the tunnels may be moist. Attacks may also be associated with mechanical damage to the trunks or limbs where equipment or automobiles have cut or bruised the bark. Such injuries are attractive egg-laying sites.

The larvae causing the damage are whitish-pink with a light brown head and are mostly hairless. They are 18 mm long when full grown. The adult moths resemble small, black- and yellow-striped wasps. There is a single generation of moths annually; emergence occurs from May to early August, with a peak in June and July.

Control on ornamental oaks is usually aimed at the exposed adults; a residual insecticide spray or paint may be effective. Scraping or rasping away the roughened bark, to improve the appearance, will also kill many larvae and pupae in their tunnels. Invigorating the oaks with judicious watering, fertilizing, and pruning may help, as will the prevention of mechanical damage to the tree.

Oak twig girdler

If one notices many small patches of dead leaves on an oak tree (fig. 10), the chances are that it is infested with oak twig girdler (*Agrilus angelicus*, Coleoptera: Buprestidae). If one traces down the twig from one of these patches of dead leaves, to the junction of the dead and living tissue, and carefully peels the bark, exposure of a flat tunnel girdling spirally down the twig in the cambium usually confirms the presence of this insect. Further, if brown powder-like frass and a 25-mm long, flat, whitish, legless larva, with expanded sides, is found in the tunnel (fig. 11), it is certain the twig girdler is present. This insect requires two years to complete its life cycle. At the end of one year, twigs about 5 mm in diameter will have been girdled and killed; each will include a relatively small number of brownish-white, dead leaves (fig. 10). At the end of

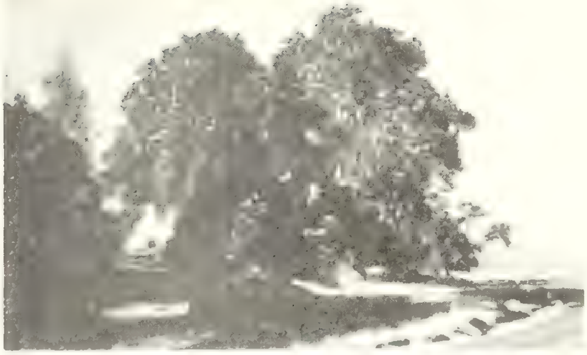

Figure 10--Notice many patches of whitish dead leaves on this coast live oak. Each patch has resulted from one year's mining of the oak twig girdler, *Agrilus angelicus*.

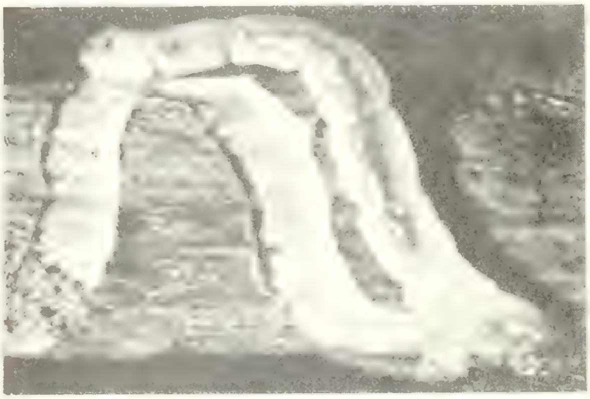

Figure 11--Mature larva of the oak twig girdler, *Agrilus angelicus*, next to its mine in the twig; bark at the junction of living and dead wood has been removed. 3.8X.

about 22 to 23 months, the larva will have girdled down into twigs 10 to 15 mm in diameter, and there will be many more dead leaves. This girdling effectively cuts through the cambium and xylem layers, and stops the flow of water and nutrients to the leaves and twigs beyond the girdle.

This twig girdler, like other buprestid beetles, seems attracted to oaks suffering from drought. Much heavier girdler infestations follow one or more years of lower than normal rainfall. This girdling damage, and the persistent, dead leaves, on an oak tree grown for ornament, is unsightly and most owners want something done about it. However, with oaks in the wild, forested environment such injury is of less concern to man. Physiologically such girdling damage may not be cause for concern, and conceivably could be even considered beneficial to the tree. It would in effect be like a pruning, which in a drought situation, could be beneficial.

After 23 months, the twig girdler larva turns back into the wood it has killed, tunnels for 100 to 150 mm, chews out a chamber and pupates therein. The adult emerges in the chamber within a week or two and chews its way to the outside of the twig, thus being exposed for the first time in almost two years. In warmer, inland areas the period of adult emergence will be from late May to late June; whereas in cooler, coastal areas, emergence will be from late June into late July. With such a two-year cycle, it should be noted that there will be even-numbered and odd-numbered year strains, with no interbreeding.

To control twig girdler in valuable oaks, first invigorate the trees with suitable irrigation, pruning, or fertilization. Second, spray a residually effective insecticide on the oaks shortly prior to adult emergence from the twigs.

Other boring insects

Dry-wood termites (*Kalotermes* species, Isoptera: Kalotermitidae)
Carpenterworm (*Prionoxystus robiniae*, Lepidoptera: Cossidae)
Pacific flatheaded borer (*Chrysobothris mali*, Coleoptera: Buprestidae)
Nautical borer (*Xylotrechus nauticus*, Coleoptera: Cerambycidae)
Roundheaded oak twig borer (*Styloxus fulleri*, Coleoptera: Cerambycidae)
Oak bark beetles (*Pseudopityophthorus* species, Coleoptera: Scolytidae)

ACORN INSECTS

Foresters and other tree managers often collect acorns for oak propagation. As much as 80 percent of these acorns may be wormy (fig. 12). Two of the most common acorn-boring insects are the larva of a moth--the filbertworm (*Melissopus latiferreanus*, Lepidoptera: Olethreutidae), and the larva of a weevil--the filbert weevil (*Curculio occidentis*, Coleoptera: Curculionidae), see figure 13. Either type of larva may tunnel throughout the inside of the acorn and

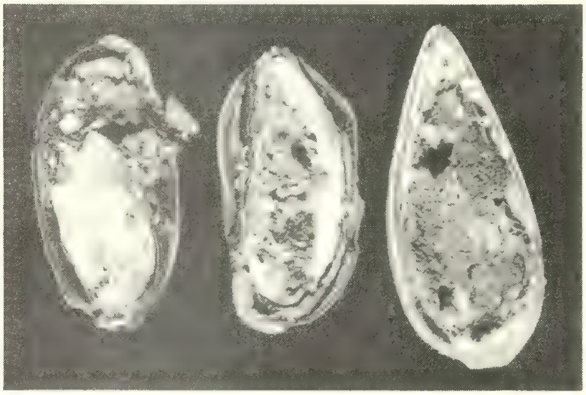

Figure 12--Three acorns cut open to show the extensive larval tunneling and frass of the filbertworm, *Melissopus latiferreanus*. 0.9X.

Figure 13--Sideview of the long-snouted adult of the filbert weevil, *Curculio occidentis*, walking on the acorn cup of canyon live oak. 2.1X.

deposit frass (fig. 12). The embryo may be destroyed and depletion of the endosperm may greatly reduce the vigor of a new oak tree. Another frequent symptom associated with insect-infested acorns is bleeding. Bleeding sap may have a sour, fermented odor from a bacterium introduced by the insect (Hildebrand & Schroth, 1967). Bleeding may be so great and the odor so strong that some homeowners with oaks may want to have the insect controlled.

The filbertworm may be distinguished from the filbert weevil larva by the true legs on the thoracic segments and prolegs, with tiny hooks (crochets) on the abdominal segments; the weevil larva is legless. The reddish-brown, metallic copper-marked filbertworm moth lays her eggs singly on the acorn and the newly hatched larva bores through the tough acorn coating.

The yellowish-brown adult weevil (fig. 13) uses the tiny mouthparts at the end of her long, slender snout, to chew a small hole in the acorn coat, and then turns around, deposits an egg and pushes it through the hole. The weevil grub hatches inside of the acorn. The filbertworm has at least one annual generation and maybe two. The larvae may be boring in the acorns from July to September and again in the fall and throughout the winter. The adults will be present up to two months prior to these periods. The filbert weevil has only a single, annual generation and may be present on the acorns in the summer and early fall, with the larvae feeding in the acorn from early fall throughout the winter.

OAK GALL INSECTS

Oaks are the favorite host of the gall wasps (Hymenoptera: Cynipidae). Over 140 species of these wasps lay their eggs in various tissues of oaks in the western United States. The oak produces a growth (gall) around the egg and developing larva that is unique in form for each wasp species. Most of these galls are an interesting novelty and cause no harm to the oak. The two leaf-infesting gall insects discussed here, however, do cause economic damage.

Two-horned oak gall

This name describes the small, wheat-grain-sized gall found on the lower leaf surface veins of coast live oak, caused by Dryocosmus dubiosus (Hymenoptera: Cynipidae). The gall frequently has a small, up-turned projection on each end (fig. 14). There is a reaction from the oviposition in the leaf vein that soon causes the leaf beyond the puncture to die, even without a gall forming. It is common to observe coast live oak with all its leaves appearing partially whitish-brown, much in contrast to the normal dark green. This detracts from the tree if it is primarily an ornamental.

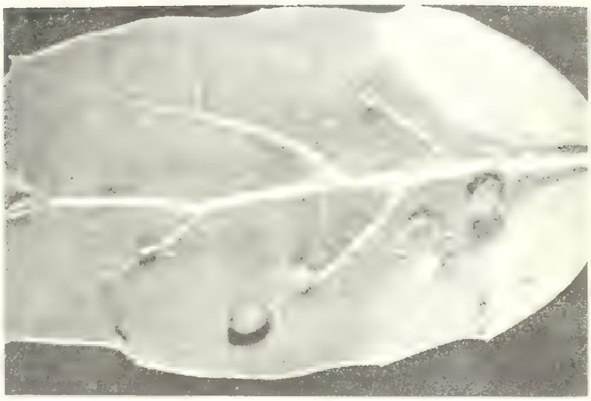

Figure 14--Lower side of coast live oak leaf with two veins infested with the two-horned oak gall caused by Dryocosmus dubiosus; several other veins show slit marks where galls have fallen off. Dead tissue is due to ovipositional punctures. 1.5X.

From each gall emerges a female wasp and many of these fly to the male flowers (catkins) and oviposit in them. Each oviposition causes the catkin to produce a club-shaped, reddish-purple gall, one of which may contain a female wasp and another the male. Individuals of this bisexual generation mate and the females oviposit in the leaf veins, causing another crop of two-horned galls containing the unisexual generation. As a timing device, it is worth remembering that the two-horned gall is producing female wasps at about the time the catkins are developing; this is about the time an insecticidal spray should be applied.

Distorted leaf gall

The leaf, leaf petiole, twig, and even the acorn, may be involved by this very irregular, roughened, and many-celled gall on white oaks (fig. 15). It is caused by the gall wasp, Neuroterus varians (Hymenoptera: Cynipidae). Many of the valley oaks in the San Fernando Valley, for example, have been damaged, both ornamentally and physiologically, by enormous populations of this gall. The leaves in particular may be so distorted, thickened, and reduced in size that they cannot carry on their normal functions of

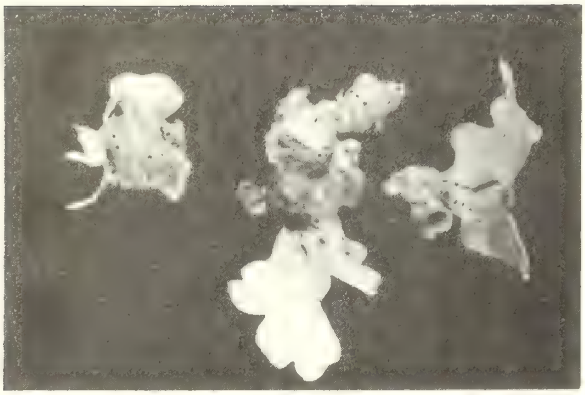

Figure 15--Severely distorted leaves and stems of valley oak resulting from galls of Neuroterus varians. 0.9X.

making food, transpiration, etc. Many homeowners complained that they were deprived of the shade and beauty of their valley oaks by this wasp's actions. Although considerable spraying of insecticide had been done during the foliage season, it was of little effect. It was not until after discovering the wasp was active before the leaves came out that control efforts became successful. The wasp oviposits in the developing leaf buds in February and early March. Insecticidal sprays at that time reduced the gall damage.

Other common cynipid gall insects

California gallfly (Andricus californicus)
Irregular spindle gall wasp (Andricus chrysolepidicola)
Live oak gallfly (Callirhytis pomiformis)
Twig club gall wasp (Callirhytis suttoni)
White oak cone gall wasp (Andricus kingi)
Spined turban gall wasp (Antron douglasii)
Jumping oak gall wasp (Neuroterus saltatorius)
Woollybear gall wasp (Sphaeroteras trimaculosum)

MANAGING OAK INSECT PESTS

It is well to remember that the oak is a very tough tree and there is probably no insect species acting alone that will kill it. Very few insect problems compare in severity, for example, with drought or armillaria root rot. After identifying the oak insect and its damage to the tree, and learning pertinent points of the pest's biology, the oak manager must decide whether or not something should be done about it. A first question to ask is: are the oaks worth the cost of the control measure? A single oak in a home yard, one that contributes considerable beauty and dollar value to the property, will easily be worth fairly costly and repeated treatment. But oaks in a wild, forest situation will probably have a much lower unit value, and cannot justify very costly pest control action. Spraying trees with insecticide, for example, may cost from $2 to $50 per tree depending on several factors. Phrasing the question differently: will the cost of doing something be less than the "cost" of doing nothing?

Another related question to be decided is: will the control measure have side effects that are not acceptable? For example, will spraying an insecticide kill the fish in a nearby lake or stream? Or, will spraying an insecticide create an unacceptable public furor? Or, will spraying kill beneficial parasites and predators of the pest insect?

If it is assumed that something should be done, the oak manager should get the services of a competent entomologist to aid in the evaluation very early in the process. As a matter of principle the use of an insecticide should always be considered as the last resort, especially in situations where it is undesirable to be committed to insecticide use year after year. Improving the vigor of the oak tree should be considered first, such as judicious irrigation, fertilization, and pruning, especially when dealing with the more damaging boring insects. Sanitation/salvage, removal of weak and dying trees as practiced in other types of forests, may not only improve the appearance and vigor of the oak stand, but may aid in insect control. Or the use of sanitation/salvage coupled with the use of insecticide, sharply focussed both in space and time, may be the most desirable. Of the various means of applying insecticides to oak trees the method known as "high-pressure" or "hydraulic spraying" is probably the most reliable. The spray equipment needed to treat a mature oak tree is large, heavy, and expensive. Commercial spray operators have such equipment for their business, and it is often least expensive to hire the job done by one of these operators.

Until very recently, the use of insecticides for woody ornamental plants had to conform exactly to what was printed on the insecticide container label. The label had to state the specific rate that could be used on a particular oak insect pest. This has meant that there were no legal recommendations for similar oak insects not mentioned on the label. Recently these regulations were relaxed so that now an insecticide can be registered: for oaks, or even just for woody ornamental plants; for a specified insect pest, or for near species; for a rate less than the maximum rate stated on the label; and for more than one method of application.

There are not many alternatives to insecticides for the *sucking insects* mentioned this paper. Tree invigoration which produces new growth tends to favor the pest insect. Pruning the tree, to the extent of good horticultural practice, opens the tree crown so that insecticidal sprays can penetrate better. Parasitic or predatory insects have obviously not been an important factor in the natural control of the sucking insects of oaks; otherwise we would not have them as problems.

To control pit scales, a single spray of any one of the following insecticides in 100 gallons of water can be used: (a) 1 pound of 50 percent diazinon wettable powder, (b) 2 pounds of 50 percent carbaryl wettable powder, or (c) 4 pounds of 25 percent malathion wettable powder plus 1 to 1-1/2 gallons of light-medium or supreme-type oil. Application should be made at peak hatch during mid-May to early June, or when seen. These sprays and timing would also serve to control crown whitefly, or any of the other sucking insects mentioned.

There are some natural enemies of the *leaf-consuming insects* mentioned in this paper, but it is questionable how well man can control their beneficial actions. California oak moth has a complement of natural enemies (Harville, 1955) which undoubtedly keep this leaf-consumer in low populations during most years. During the occasional year when the California oak moth populations explode, insecticidal spraying may be necessary. In those areas where fruittree leafroller has been damaging, natural enemy activity has not been prominent, but leafroller itself exerts a built-in control in that large, early-emerging worm populations consume the desirable foliage leaving none for the late emerging worms; but this may be little solace for those owning the oaks.

If spraying of insecticides is acceptable, carbaryl at the rate of 2 pounds of 50 percent wettable powder per 100 gallons of water may be used against oak moth; 1-1/4 pounds of 80 percent carbaryl sprayable would be an alternative. Either of these sprays would also be useful against fruittree leafroller or tent caterpillars, or several of the other leaf-consuming insects mentioned. An environmentally safer spray option for California oak moth is the use of *Bacillus thuringiensis*, which affects only certain insects and only at certain stages. Per 100 gallons of water use 1 gallon of Thuricide® 90 TS, or 3 pounds of 25 percent Biotrol® wettable BTB 183, when larvae are about half grown.

Tree invigoration is a first line of defense against *boring insects*. This may be by judicious watering, pruning, or fertilizing. Second, a residually effective insecticide spray can be applied shortly before the adult insect comes out of the bored trunk or limb. On oak twig girdler or western sycamore borer this may be 2 pounds of 50 percent carbaryl wettable powder, or 1-1/4 pounds of 80 percent carbaryl sprayable, per 100 gallons of water. For twig girdler this should be applied about mid-May in inland areas to mid-June in cooler coastal areas. Pruned, girdled twigs can be confined in a screen cage under the tree and watched for adult emergence from the twig. For western sycamore borer this spray may be applied in late May; by observing the bored area the adults will begin revealing their presence by the protruding pupal skins. Other boring insects listed may have other adult emergence dates.

For controlling *acorn insects* on the tree, there is a legal registration for filbertworm using carbaryl spray, at the rate of 2 pounds of 50 percent wettable powder per 100 gallons of water. This is for the adult moth which has been collected in mid-April, on oak gall apples, and again in mid-October on the acorn. This registration does not mention the filbert weevil although carbaryl is used to control other weevils. Control of these two insects in the acorns after they are harvested can be accomplished with the fumigant, methyl bromide, at the rate of 5 pounds per 1000 cubic feet, at 70° to 79°F, with 4 hours exposure, at atmospheric pressure, and in a chamber, van container, or under a tarpaulin. Of course, methyl bromide is an odorless gas and is very toxic to humans, so adequate precautions must be taken. The larvae can be killed in the acorns with wet or dry heat but this also would likely kill the oak embryo. Acorns held in cold storage will retard the development of the insects.

Carbaryl, at 2 pounds of 50 percent wettable powder per 100 gallons of water, also is effective against the adult stage of the *gall insects*. Such a spray should be applied in early February for the distorted leaf gall wasp, and about mid-March to early April for the two-horned oak gall wasp. The timing of sprays for other gall wasps will vary depending on the species.

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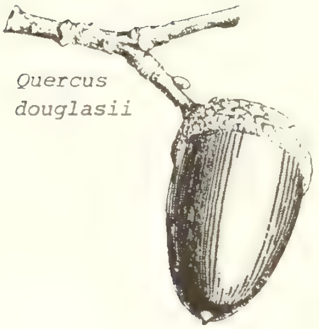
Quercus douglasii

Diseases of Oaks in California[1]

Robert D. Raabe

Abstract: Diseases of native oaks in California are of little importance under natural conditions. Root rots resulting in decline and/or death are very severe when native oaks receive summer irrigation. Witches' broom may also be severe on oaks when pruned, fertilized, and irrigated during the growing season.

Diseases of oak trees in California are relatively unimportant when the plants are grown under natural or native conditions. This is due in part to the fact that the soil-borne disease-producing organisms are not too important under natural conditions. It is also due in part to the long dry period in most of California. Most of the disease-producing organisms which affect the foliage need condensed moisture on the leaves over a prolonged period in order for infection to occur. Dew formation is usually not of long enough duration to allow such organisms to become established. The most important diseases of oaks occur when the trees are grown under cultivation and are treated improperly. Irrigation of trees during the summer favors certain disease-producing organisms.

The diseases to be included here are separated into those that are soil-borne and affect the root systems and those that infect the above-ground parts of the plants. The importance, general symptoms, and control measures, if necessary, are mentioned for each disease.

SOIL-BORNE DISEASES

Seedling Root Rot

This disease is most common in nurseries when the seedlings are grown in containers. Young trees die, usually during the summer season. An examination of the root system reveals many darkened and dead roots. Removal of the bark on the main stem shows a brown discoloration moving up into the woody tissues. The disease results from the fact that native oaks, because they have adapted to a climate where there is no summer rainfall, do not need irrigation during that time. However, when grown in containers where the root systems are confined and cannot explore the open ground, the plants must be watered to keep them alive. This weakens the plants. If water molds (species of Pythium and Phytophthora) are present, they will invade the root systems and weaken the trees resulting in stunting or maybe death. Control is difficult. Not overwatering, keeping plants on the dry side, and using soil mixes with excellent drainage will help. Periodic drenches with fungicides effective against such fungi have given control in other native California plants and plants native to areas with dry summers (Raabe and Lert 1967).

Decline and Trunk Canker

By far the most important disease problem on native oaks is a decline in which the trees may die rapidly, or more commonly, in which the trees decline and linger a long time before they die. Symptoms include sparseness of foliage, loss of foliage color, death of variable numbers of smaller branches, various size cankers at the soil line, and death of the tree. Cankers may be inconspicuous or may appear as ruptures in the bark, at or near the soil line, from which a dark sticky material may exude.

Little research has been done regarding the cause of the disease. Miller (1941) reported the isolation of Phytophthora cactorum (Lebert & Cohn) Schroet. from diseased trees and in subsequent inoculations showed the fungus to be pathogenic to Q. agrifolia and Q. virginiana. He also reported observing that excessively wet soil conditions due to prolonged rains, overwatering, poor drainage and raising of the soil level on the main trunk favor the disease Mircetich et al. (1977)

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[1] Presented at the Symposium on the Ecology, Management and Utilization of California Oaks, Claremont, California, June 25-27, 1979.

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reported the isolation of Phytophthora citricola Sawada and P. cactorum from bark and roots of declining Q. agrifolia trees and from the soil around infected trees. They also isolated P. cinnamomi Rands from cork oak, Quercus suber. In greenhouse inoculations using young seedlings, they found both Quercus sp. to be infected by all three species of Phytophthora, though the fungi did vary in their virulence on the different oaks.

In isolations from small roots of declining oaks taken from soil agar samples, unidentified species of Pythium and Phytophthora have been recovered, indicating that they as well as the larger roots and stems may be infected by these fungi.

The importance of summer irrigation as the most important contributing factor cannot be over-emphasized and has been stressed by Miller (1941), McCain and Raabe (in Brown et al. 1975, Butterfield et al. 1963) and Mircetich (1977).

On the U.C. Berkeley campus, excellent illustrations of this have been observed, the most striking of which occurred outside the new Moffet Library. Two California live oak trees, each about 30 cm dbh, were left in place during construction of the building. Upon completion, landscaping called for mounds on either sides of trees, lawn planted up to the trunks and sprinklers to irrigate the lawn. In 1971, this was completed. The tree nearest the sprinkler immediately started to decline and in 1974, the tree died and was removed. The second tree showed a slower decline but by 1977 was very weak. Because of the drought very little irrigation of the campus occurred that year. By early winter, the tree had recovered to the point where it did not look as though it had ever suffered decline. This is a textbook example; it is known that withholding irrigation for one summer does not always result in such a miraculous recovery but withdrawal of summer irrigation will help give control.

Oak Root Fungus

Another fungus which infects the roots of oak trees is Armillaria mellea (Vahl ex Fr.) Kummer. This fungus is commonly called the oak root fungus, not because it often kills oaks but because the roots of native oaks frequently are infected with little apparent damage to the trees under natural conditions. The fungus received its name because orchard and vineyard crops frequently died when planted in land recently cleared of native oaks. The fungus found in the dying and dead plants was the same as the fungus found in the oak roots left in the soil and because of this association, it received its name.

Although the oak root fungus is important as a disease-producing agent in many plants, the amount of damage on California oaks has not been determined. Under natural conditions, the fungus does not seem to damage California oak trees. However, infected trees, in irrigated areas or in areas where the soil level has been changed, frequently die. The abundance of layers of white fungus tissue between the bark and wood of the lower stems and larger roots (fig. 1) suggests the importance of the fungus in weakening the trees. Recently a tree next to a lawn in a large park blew down in a wind. Not only was the fungus present between the bark and the wood of the roots but many of the roots showed advanced stages of decay in which the wood had become quite soft and watery with patches of fungus tissue scattered through it. Few other fungi produce similar fungus structures when plants are infected. If in question as to whether the oak root fungus is the cause, smelling the fungus tissue can help identify it, for the oak root fungus has a distinct mushroom-like odor.

Another indication of the presence of the fungus includes the production of dark, root-like strands on the outside of infected roots. These rhizomorphs, as they are called, are important in the infection of roots. They are often similar to small roots but can be distinguished from them easily by soaking pieces of rhizomorphs in household bleach diluted one part in nine parts of water for 10 minutes. If it is an active rhizomorph, the internal portion will become bleached a pure white. The centers of roots will not do this.

Other evidence of the presence of the oak root fungus is the production of mushrooms, usually around the bases of infected plants. These mushrooms vary in color from pale tan to red-brown and in size from 2.5 to 15 or 17.5 cm in diameter. In California, they usually appear between the middle of November and the middle of January. Although spores are produced in abundance in these fruiting bodies, they are not important in the spread of the fungus. Spread is mainly by contact of roots with other roots, either living or dead, in which the fungus is active.

Many oaks have been listed as being infected by the fungus throughout the world (Raabe 1963) but only a few have been tested for resistance to the fungus (Raabe 1975). In such tests, Quercus ilex and Q. lobata have been found to be highly resistant, Q. chrysolepis was found to be moderately resistant and

Q. dumosa and Q. virginiana (the only non-native oak to be tested) have been found to be susceptible. Additional oaks need to be tested in this program (Raabe 1966).

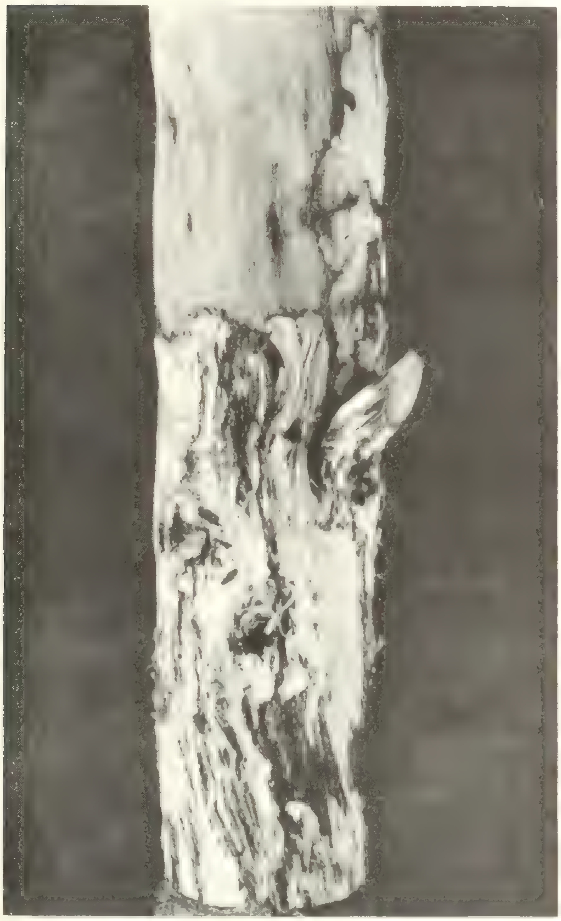

Figure 1--A portion of a root with the bark removed showing the layer of white fungus tissue of Armillaria mellea between the bark and the hard wood.

Control of Armillaria mellea under urban situations is very difficult. In orchards and vineyards, methyl bromide fumigation has given some success. In urban areas, this is not feasible. Avoidance of summer irrigations and the maintenance of existing soil levels around established trees will help. If changes in soil levels are necessary, dry wells around the trunk should be made so that the soil level 60 to 90 cm away from the bases of the main trunks will not be changed.

Inasmuch as the fungus exists only in infected roots in the soil, the removal of such roots prior to planting will help give control. The more complete the removal, the better the control. The use of resistant plants also will help control the fungus (Raabe 1975).

Verticillium and Fusarium Wilts

It should be mentioned that there are unconfirmed diagnoses of Verticillium wilt (Verticillium albo-atrum Reinke & Berthe.) and Fusarium wilt (Fusarium oxysporum species as yet unnamed) in California live oak trees. Although there is a report (Ivanchenko 1957) of a wilt in oak trees in Russia in which a Fusarium sp. was found, it was isolated in conjunction with three other fungi, all four of which had to infect the tree before the wilt symptoms appeared. There is also a report of a vascular wilt of oak resulting from infection by Fusarium oxysporum in Romania and Russia (Georgescu and Mocanu 1956) but the fungus was found only in seedlings. In personal communication with Dr. W. C. Snyder and Dr. Shirley Smith of the University of California, Berkeley (recognized authorities on Fusarium wilts), they stated they knew of no Fusarium wilts in oak trees, particularly California oaks. In regard to Verticillium wilt, a survey revealed a report of Verticillium on oak in Russia (Kranzouz 1958) and also a report from Hungary (Georgescu et al. 1959), but no reports of Verticillium on any oaks in the United States. This was corroborated by Dr. Stephen Wilhelm (an authority on Verticillium wilt) of the University of California, Berkeley. Trees reported to be infected by these fungi should be checked by the University, State or Federal plant pathologists to determine the validity of the diagnoses.

DISEASES AFFECTING ABOVE-GROUND PARTS

Slime Flux

This disease, which results from infection of wounds by bacteria and various fungi, occurs where sap or water can collect. It is usually more severe in large branches. As the organisms utilize the sap, they give off by-products which prevent the cambium from healing the wound. More sap collects, more organisms develop and the process continues. Frequently a dark liquid flows from such wounds and may stain branches or the main trunk clear to the ground.

Control results from pruning in such a way that no liquids can collect in the wounds. In old wounds where this is occurring, the wound should be scraped to expose good wood and should be fixed so that all liquids drain from it. It has been suggested that painting such wounds with Bordeaux or a fixed copper paste will help.

Powdery Mildews

The powdery mildews are a group of fungi which are completely external on the surfaces of infected plants except for small extensions into the epidermal cells for the purpose of nourishment. The fungi are so named because the vegetative growth including the spores has a powdery appearance. Unlike most fungi, the powdery mildews do not require condensed moisture for the spores to germinate. The powdery mildews actually are favored by warm days, cool nights and reduced light intensities. In California, there are four powdery mildews found on oaks and only the one which causes witches brooms is of importance. The causal fungus is Sphaerotheca lanestris Harkn., though it sometimes is listed as another fungus (Gardner et al. 1972). It frequently infects the new growth of plants (table 1) and when it does, it stimulates lower lateral buds to develop, resulting in a witches broom, all of which is covered by the white, powdery growth of the fungus (fig. 2). Infected leaves become distorted and somewhat brittle. This disease rarely occurs on trees growing under natural undisturbed conditions. It is favored by conditions such as irrigation, fertilization and pruning of trees, which promote new growth late in the growing period during summer and fall. Sprouts following forest fires frequently are infected and develop witches brooms which may then become infected. Because the disease results primarily from poor cultivation practices, control results from cultivation practices which do not favor the disease. Leaf infection by the same fungus results in the brown mildew which appears as a brown, felt-like growth on the undersides of the leaves. Though it is conspicuous, it does not damage infected trees. Many oaks are infected and those reported as susceptible are listed in table 1.

Erysiphe trina Harkn. is recorded only on two oaks. On these plants, it produces conspicuous roundish infected areas on the upper surfaces of leaves (fig. 3). These infected areas frequently are covered with the sexual fruiting stages of the fungus, giving a grey appearance to the infected areas. Two other powdery mildew fungi also are found on oaks in California. These form a white, powdery-like growth, sometimes interspersed with the small, dark, spherical sexual fruiting bodies of the fungi, usually on the older leaves of various oaks. Susceptible species are listed in table 1. Because these mildews do little damage, control is not necessary.

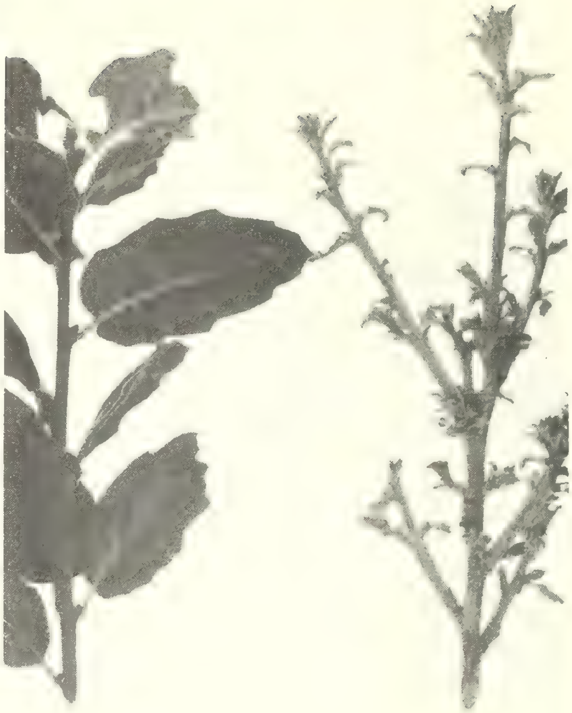

Figure 2--Quercus agrifolia branch tips, showing powdery mildew witches broom on the right and non-infected branch tip on the left. Photo courtesy of C. E. Yarwood.

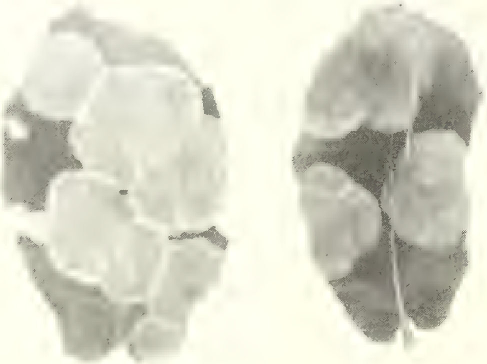

Figure 3--Leaves of Quercus agrifolia infected with the powdery mildew fungus Erysiphe trina. The infected portions on the leaf on the right are darker due to the production of the sexual fruiting bodies of the fungus. The evidences of the fungus on these leaves are more pronounced than usually found. Photo courtesy of C. E. Yarwood.

Table 1--Susceptibility of oaks to four powdery mildew fungi in California (Bonar et al., Gardner and Yarwood 1978) [1]

Erysiphe trina	Sphaerotheca lanestris (Brown mildew and witches broom)	Microphaera alni	Phyllactinia corylea
	Native oaks		
Q. agrifolia	Q. agrifolia*	Q. agrifolia	Q. agrifolia
Q. chrysolepis	Q. chrysolepis*	Q. douglasii	Q. durata
	Q. douglasii	Q. durata	Q. lobata
	Q. dunnii	Q. engelmanii	Q. turbinella
	Q. engelmann	Q. garryana	
	Q. garryana	Q. kelloggii	
	Q. keloggii*	Q. lobata	
	Q. lobata	Q. turbinella	
	Q. wislizenii		
	Introduced oaks		
	Q. alba	Q. robur	Q. coccinea
	Q. cerries		Q. robur
	Q. coccinea		
	Q. ilex*		
	Q. laurifolia*		
	Q. macrocarpa		
	Q. mongolica		
	Q. nigra*		
	Q. obtusa		
	Q. palustris		
	Q. phellos*		
	Q. robur		
	Q. rubra		
	Q. suber		
	Q. velutina		

* species on which witches brooms have been reported (Gardner et al. 1972)

[1] Obtained from Bonar et al; Gardner and Yarwood, 1978.

Sooty Molds

The sooty molds are dark fungi which grow on the surfaces of plant parts, obtaining their nourishment from sugary materials either from excretions of insects such as aphids, scale, or white fly or from secretions of the plants. They do not attack the plant tissues but they are detrimental in that they may shade the leaves, thus stunting the growth somewhat, and they are not aesthetically pleasing. Control results from insect control.

Leaf Blister

This disease, resulting from infection by the fungus Taphrina caerulescens (Mont. & Desm.) Tul., has been reported only on Quercus agrifolia, Q. douglasii and Q. lobata (USDA 1960). The symptoms appear as more or less rounded, light green, slightly raised blisters about 6 to 12 mm in diameter on the upper surfaces and concave areas on the undersides of infected leaves. The layman may confuse these symptoms with those caused by an eriophyid gall mite. The blistered areas may be numerous enough to be confluent and, if so, leaf curl may result followed by defoliation. The fungus is favored by cool, wet weather after new growth has started in the spring. In California it is of little consequence and control measures have not been determined.

Rust

The rust fungus, Cronartium quercum (Berk.) Miyabe ex Shirai has been reported on Quercus agrifolia, Q. chrysolepis, Q. dumosa, Q. engelmanni, Q. garryana, Q. kelloggii, and Q. wislizenii in California (Bonar et al. unpub.). The fungus produces yellow spores on the undersides of the leaves. These spores are the repeating stage and can infect other oaks. Resting spores rarely are produced; however, when they germinate, the spores produced infect the alternate hosts which are 2- or 3-needled pines. The rust is of little importance in California and control measures are not needed.

Anthracnose

This disease results from infection by the fungus Gleosporium quernum Harkn. (USDA 1960). The fungus produces a leaf spot and a twig blight on young twigs but is not important as a disease-producing agent in California.

Septoria Leaf Spot

This is another fungus leaf spot of oaks and in California is of little consequence. The fungus Septoria quercina Desm. has been reported on Quercus chrysolepis and Q. wislezenii (Bonar et al. unpub.) and S. quercicicola Sacc. has been reported on Q. agrifolia (USDA 1960) on which they produce small, circular spots on infected leaves. When severe, these fungi may cause defoliation but generally, they cause little or no problem in California.

Heart Rot

Heart rot is a disease in which any of a number of fungi gain entrance to the heartwood through wounds including those caused by fire or dead branches. In California, Ganoderma applanatum (Pers.) Pat., Polyporus rheades (Pers.) Fr., P. sulphureus Bull. ex Fr., P. gilous (Schw.) Fr., P. versicolor L. ex Fr., Poria andersonii fasciatum Schw., S. gauspatum Fr., S. hirsutum Willd. ex Fr. and S. rugosum Pers. ex Fr. plus many other fungi have been reported as being associated with heart rots (Bonar et al. unpub., USDA 1960). Once inside, they develop in the heartwood reducing its strength and predisposing the tree or parts of it to windthrow. Although this is a disease of older trees, sometimes younger trees become infected. In standing trees, heart rot is evidenced principally by the production of fungus fruiting bodies on the outer sides of infected trees. These may be fleshy or they may be woody. The importance of the disease is dependent upon the nearness to areas where damage will result from falling trees or portions of them. Control is based on this danger and removal of portions or all of infected trees may be necessary.

Drippy Nut

This disease results from infection of developing acorns of Quercus agrifolia and Q. wislizenii by a bacterium which produces a sticky material that drips from infected nuts. The material is unpleasant, especially when it drips on cars, walks, driveways, garden furniture, patios, etc. The drippy stage of the disease is more prevalent during the warmer part of the year. The disease was first recorded by McCain and Raabe (in Butterfield et al. 1963) and in studies by Hildebrand and Schroth (1977), the causal agent was named Erwinia quercina. According to Koehler (1978), the causal bacteria gain entrance when acorns are stung by cynipid wasps, acorn curculios or probably other insects during egg-laying or feedings. No control is available at present though Koehler 1978 suggested finding a way of defruiting landscape trees as a means of control.

Mistletoe

In California, the leafy mistletoe Phoradendron villosum Nutt. is found attacking many oaks. This parasite produces a small branched plant with evergreen leaves. At the point of attachment, there may be a swelling of the host branch and an occasional dying of portions of the infected branch distal to the point of attachment. The fruits of the mistletoe are attractive to birds and the seeds, which have a sticky mucilaginous coating, may go through the digestive tracts unharmed or may stick to the bills and be disseminated in this way. Even though the leaf mistletoes are perennial, they do little damage to plants and control generally is not necessary. Where desirable, infected branches can be removed or, according to Milton Bell[3] they can be controlled by cutting the parasite from the plant and covering

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[3/] Personal communication with Milton Bell, formerly of Univ. Calif. Agricultural Ext. Service.

the point of attachment by wrapping it with roofing paper for an extended period of time.

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Quercus agrifolia

Response of Oaks to Fire[1]

Tim R. Plumb[2]

Abstract: Management of oaks requires knowledge of tree response to fire. This knowledge is gathered through visual and other evidence of damage and of recovery or death of the tree under various conditions such as fire conditions, weather conditions, and tree characteristics, particularly bark properties. Published information and field observations of five southern California oak species indicate that significant differences in oak species' fire sensitivity warrant consideration. The degree of trunk damage sustained is important. Coast live oak (Quercus agrifolia Nee) is extremely fire resistant, while canyon live oak (Q. chrysolepis Liebm.) almost self-destructs because of its dry, flaky bark. Bark thickness data are presented as well as methods for determining tissue viability. Recommendations for cutting or leaving damaged trees are based on species, size, and degree of trunk damage.

INTRODUCTION

Various oak species make up a large part of the plant cover on 15 to 20 million acres (6 to 8 million ha) in California. They occupy a wide range of sites as members of several vegetation types (Munz and Keck 1959). In the hot, dry, summer climate typical of most of California, oak trees are subject to wildfire wherever they grow. Consequently, management of the oak resource must consider tree response to wildfire.

Although the effect of fire on oaks has been studied in eastern United States (Loomis 1973, Hepting 1941, Toole and Furnival 1957), the only major report for California has concerned conifers (Wagener 1961). General studies have dealt with response of oak to damage from various sources, including fire, and it is well documented that most oak species vigorously resprout from the root crown and below-ground bud zone (Longhurst 1956). Stump sprouting potential, based on site index and tree age and diameter, has been developed for some Eastern oak species (Johnson 1977).

Historically, fire is considered a serious threat to oak trees (Edwards 1957, Sander 1977). This is understandable where the primary forest product is a veneer or high quality sawlog. Fire damage may immediately or eventually reduce the value of a tree. In California, however, other "products"--such as wildlife enhancement, watershed protection, recreation, and aesthetic value--may be more important than potential wood products. Oak trees may survive several damaging fires and live for 100 to 200 years or more. During this time, they may still provide many of the nonwood values mentioned.

Postfire oak management decisions must be made on a basis of specific information. After a severe crown fire, when all that remain are the charred trunk and large branches of the trees, it would seem obvious that the most appropriate action would be to cut the trees for firewood. On the other hand, after a low-intensity fire which causes little apparent injury to the trees, it would seem that they could be left to grow to old age. However, the apparent course of action may not always be the best postfire management decision.

This report, after some comments on fire-plant relationships, describes influences on tree response to fire, and the specific fire response of five oak species, with respect to the trunk and aerial crown. (Damage to the root crown and below-ground part of the tree is not considered here.) A brief outline of postfire oak management planning considerations is included.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Plant Physiologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, Calif., stationed at Riverside, Calif.

DETECTION OF DAMAGED TISSUE

To make an accurate assessment of fire damage, the observer must be able to distinguish between live and dead tissue. It is readily apparent when leaves are heat killed by fire. Damage to buds (if present) and to the live inner bark and cambium of the trunk and branches is not always so obvious. Several methods of detecting damaged plant tissue are listed in table 1.

Visual Evidence

It can be assumed that the cambium of a tree trunk has been killed if the bark has been completely consumed or if the bark has cracked and separated from the wood. When the bark, although completely charred, is thick, intact, and firmly attached to the wood, it is necessary to cut through the bark to determine the condition of the cambium. If the inner bark has a yellow tone, not white or pink, the cambium is either dead or seriously injured. The cambium and wood may also be stained dark brown or black, even though the inner bark appears healthy. It has not been determined that stained tissue is definitely dead, nor how long after the fire the staining occurs. Because many other damage symptoms occur within 3 weeks after a fire, it is probable that staining does also.

Table 1--Methods of detecting fire-killed plant tissue

Method of detection	General procedure	Utility[1]	Reference
Visual	1. Directly observe degree of charring of tree trunk	Quick, simple, but success depends on species and d.b.h.	Loomis 1973
	2. Cut through bark to wood; dead inner bark is yellow or black, cambium black	Time consuming, but simple and fairly definitive; time after fire for effect to develop is unknown	Hare 1961
Aroma	Cut through bark to wood; dead inner bark has distinct fermented aroma	Time consuming, but simple; confirms visual detection	
Chemical	Cut into tissue, apply chemical solution:	Quick, but so far inconclusive	
	1. Urea peroxide plus orthotolidine (1 percent solution in 95 percent methanol); healthy tissue should turn blue or blue-black	Color response erratic or none at all when tested	Hare 1965b
	2. Tetrazolium chloride; healthy tissue should turn red	No color response when tested	Danielson 1972 (for Douglas-fir seed)
Electrical	1. Measure difference in electrical resistance of healthy and damaged tissue with a voltmeter	Not tested; reported results in literature inconsistent	Hare 1960 Hare 1961 Skutt and others 1972
	2. Use square wave generator and oscilloscope; to observe wave pattern of live and dead wood	Not tested; can be done with a portable unit	Ferguson and others 1975 (for dormancy in nursery stock)

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[1] Unless otherwise indicated, evaluation is based on tests made for this report.

Other Evidence

In the damaged inner bark of oak, the aroma of a wine cask has been detected from 2 weeks to several months after a fire; neither the minimum time it takes this aroma of fermentation to develop nor its duration is presently known. This test can be used when the inner bark is cut into to inspect for tissue damage.

Under some conditions, healthy plant tissue can be distinguished from damaged tissue by chemical reaction that produces a differential color response (table 1). With the urea peroxide, ortho-tolidine, methanol method (Hare 1965b), healthy tissue should give a blue to blue-black response, whereas non-respiring, presumably dead tissue, should remain colorless. So far, I have not found the color differential clearcut. Often a mottled blue stain is obtained, so that it is impossible to separate live and dead tissue with any certainty. At present, I do not recommend these chemicals for field use.

Tetrazolium (2,3,5-triphenyl tetrazolium chloride), used to determine viability of some seeds (Danielson 1972), is said to form an insoluble red pigment in live, respiring tissue. This chemical gave no color reaction in tests of either live or dead tissue, and is not recommended.

Measurement of electrical resistance has been used to identify live and dead tissue (Hare 1960, Various as cited in Hare 1961, Skutt and others 1972). Because the reported results are somewhat inconsistent and I did not test this method, I do not recommend it.

CONDITIONS AFFECTING TREE DAMAGE

The amount of damage that occurs in trees exposed to fire depends on the interaction of many conditions, the most important of which are briefly described here.

Temperature

The length of time that living tissue can withstand high temperature is inversely proportional to the temperature to which it is exposed (Martin and others 1969). Although there is some difference in heat sensitivity between individual cells and intact plants and between various plant species, a range of fairly low temperatures is fatal to most plant tissue. Lethal temperature for most intact plants ranges between 110 and 139° F (43 to 59° C), according to Hare (1961), who cites work with pine seedlings (Baker 1929):

Temperature (°F)	Time (min)	Effect
120	10+	No injury
125	5	Death
130	2	Death

First, there is a threshold temperature below which continuous exposure will not cause death; in this example, lethal temperature is somewhere between 120° F (49° C) and 125° F (52° C). Second, as the temperature increases, it takes less time to cause death. At 135° F (57° C), seedling death is rapid. A temperature of around 125° F is considered fatal to the cambium.

Fire Characteristics

Fire behavior, in rate-of-spread, energy release rate, and residence time, affects the time-temperature response, and thus the amount of tree damage that occurs. The time-temperature relations for the fire, the bark surface, and the cambium are not the same (fig. 1).

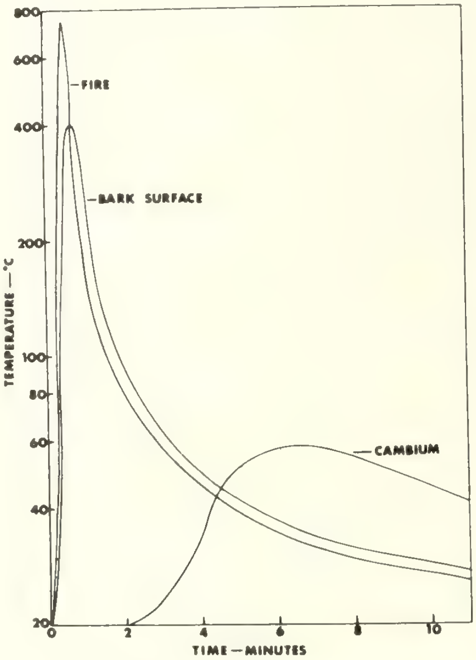

Figure 1--Time-temperature relations resulting from a passing fire can be predicted for two different locations in the tree trunk (Martin 1963).

Differential Heating

Not all sides of a tree are exposed to the same heat load. An eddy (chimney) effect develops on the lee side of a tree from the direction the fire is moving. This has been amply demonstrated under laboratory conditions by Gill (1974) and duplicated in our laboratory (fig. 2). In the field, trees with basal wounds on only one side of a tree, usually the uphill side, may be observed.

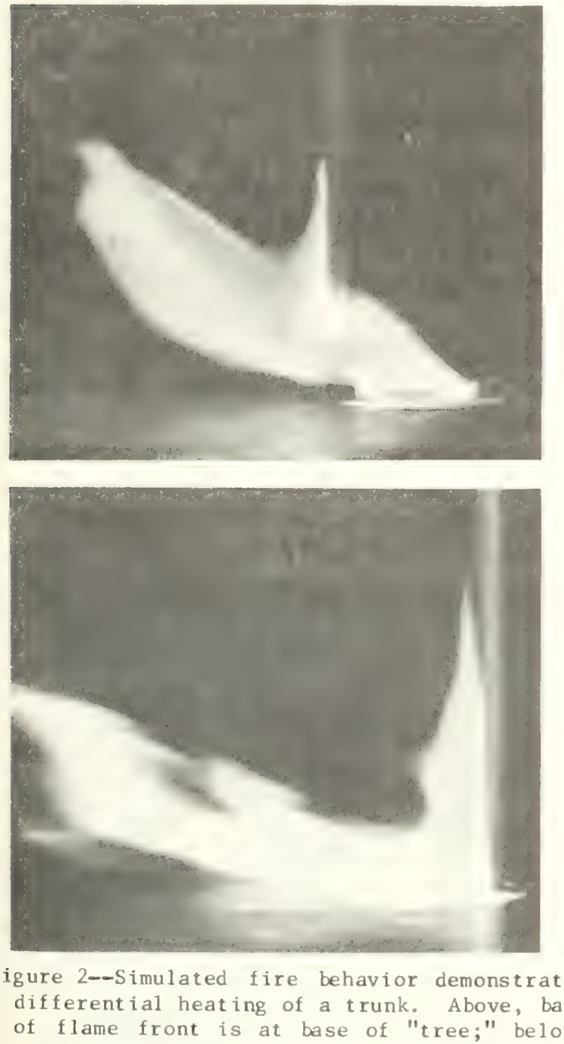

Figure 2--Simulated fire behavior demonstrates differential heating of a trunk. Above, base of flame front is at base of "tree;" below, base of flame is completely past tree.

Ambient Temperature

The initial bark temperature may determine whether or not the cambium is killed. For example, Hare (1965a) found that longleaf pine (Pinus palustris Mill.) and sweetgum (Liquidambar styraciflua L.) were about 50 percent more resistant to fire at 35° F (2° C) than at 70° F (21° C).

Season of the Year

Work with California conifers indicates that fire damage potential is greater in the growing season than later in the summer (Wagener 1961). Both eastern conifers and hardwoods, including oaks, showed increasing fire effects from winter to spring to summer (Ferguson 1957). This seasonal effect may be due to (1) differential physiological sensitivity to heat, (2) differences in fire intensity, and (3) differences in initial temperature, ambient temperatures being lower in spring than in summer.

Tree Characteristics

Predicting tree response to fire requires knowledge of certain facts about the tree, primarily, its species, age, diameter, and height; the tree part affected; and the bark characteristics.

In assessing fire damage, it is important that the species of oak be identified correctly, because all oak species do not have the same resistance to fire or the same recuperative capacity after being burned (Hare 1961, Spalt and Reifsnyder 1962). Differences in heat tolerance are probably due to differences in bark thickness, composition, chemical content, and other traits. See the discussion of the specific response of five southern California oak species to fire in a later section.

Tree age influences resistance to heat damage—younger trees are more susceptible to stem and top kill than old trees. Directly correlated to tree age are tree height, d.b.h., and bark thickness. Bark composition also changes with age, and may increase or reduce a tree's susceptibility to fire.

Tree diameter, which is directly related to tree age and site quality, is important in determining trunk survival. Large trees are more resistant to fire damage than small trees (Ferguson 1957). They have greater capacity as a heat sink and usually have thicker bark. Most oaks, including coast live oak, if less than 6 in. d.b.h. will be top-killed by a hot fire. Seedlings and trees less than 2 in. diameter will be top-killed by most fires.

Tree crown height directly affects amount of fire damage. Tree species which attain large size may suffer little or no crown damage from a low intensity fire if the lower edge of the crown is 30 to 40 ft (9 to 12 m) above the ground. Shrubs and small trees usually sustain heavy crown damage or complete trunk and crown kill during most fires.

Not all *tree parts* are equally sensitive to fire, although individual cells will be killed at 125° F (52° C). The size of a material--its surface to volume ratio--influences its susceptibility to heat damage. Leaves with a high ratio are much more susceptible to damage than twigs and other parts with much lower ratios. The trunk and branches are also protected by a corky layer of bark, which is a good insulator (Spalt and Reifsnyder 1962). Even a thin layer of bark will give good protection from high temperature for a short time--see the discussion below.

The roots are protected by a corky outer layer and by the soil itself. Oak root systems generally suffer little direct heat damage except possibly in feeder roots near the soil surface. It is probable that part of a root system dies back in response to aboveground damage, but this has not been verified in the field.

Dormant bud meristems have a thin protective covering of bud scales which reduces their sensitivity to heat damage as compared to leaves. I observed this after a prescribed fire in late spring in San Diego County in which the leaves of California black oak (*Q. kelloggii* Newb.) trees were killed. New shoots emerged from the damaged branches within 2 weeks after the fire. Acorns are quite sensitive to heat; even those lying on the ground exposed to sunlight are soon damaged.

Bark Characteristics

Bark is the most important protection the cambium has against damage from fire, insects, cold, and mechanical injury. It is a natural insulator containing numerous air spaces and suberized corky tissue.

The bark develops into a complex structure as a tree matures, changing from a thin layer of epidermal cells in young tissue to a thick, complex, multilayered zone in old stems. The general internal structure of a tree is illustrated in figure 3.

The outer bark varies greatly in *surface texture* from one species to another and is greatly affected by tree age. Surface texture may influence a tree's response to fire. A dry, flaky surface may actually contribute to a fire's intensity and result in more damage than would occur to a tree with smooth bark exposed to the same external heat input. In fact, the rise of cambial temperature during a fire is probably directly related to the flammability of the outer bark (Gill and Ashton 1968). I have frequently seen coast live oak (smooth bark) show only surface charring while canyon live oak (flaky bark, fig. 4) was frequently burnt through to the wood. Under intense burning conditions, coast live oak is damaged only 1/2 to 3/4 in. (1.3 to 1.9 cm) into the bark. Similar results from different bark surface textures were reported for eucalyptus (Gill and Ashton 1968).

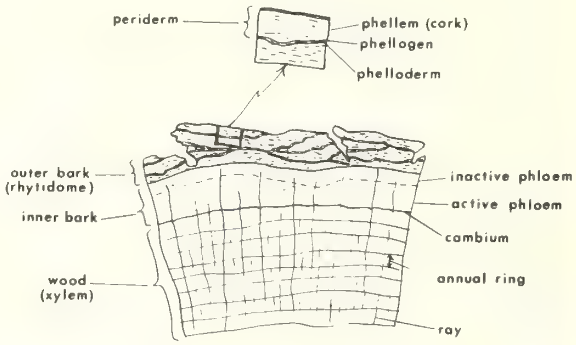

Figure 3--Tree response to fire is partly determined by the nature of the primary components of the bark and trunk.

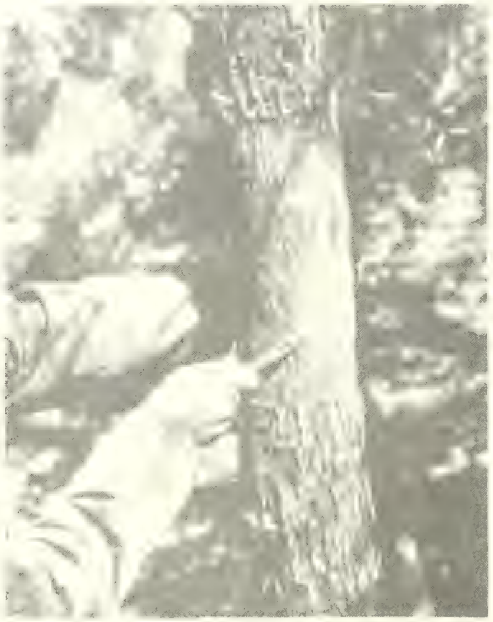

Figure 4—Bark surface texture may affect fire behavior. The dry, flaky outer bark of canyon live oak increases fire intensity and amount of heat reaching the trunk.

The most important single influence on tree sensitivity to fire is bark thickness. Bark thickness is directly related to d.b.h. (Hare 1965a, Gill and Ashton 1968), and to tree age (Spalt and Reifsnyder 1962). Hare (1965a) found, using a constant heat source, that it took the cambium of an oak 30 seconds to reach 140° F if the bark was 0.2 in. (5.0 mm) thick and 136 seconds for bark 0.4 in. (10.0 mm) thick.

I collected bark thickness data for five southern California oak species. Differences in bark thickness among the five species are apparent (fig. 5). Coast live oak not only has the thickest bark, but its living, inner bark is several times as thick as its dead, outer bark. Interior live oak (*Q. wislizenii* A.DC.) likewise has a high ratio of inner to outer bark while the other species have about an equal amount of inner and outer bark. Other work indicates the older trees have greater heat resistance, not only because the bark is thicker, but also because the proportion of dead bark is greater (Hare 1965a, ref. to thesis by D. D. Devet 1940). However, the high fire resistance of coast live oak contradicts the idea that more dead bark is necessary for good fire resistance.

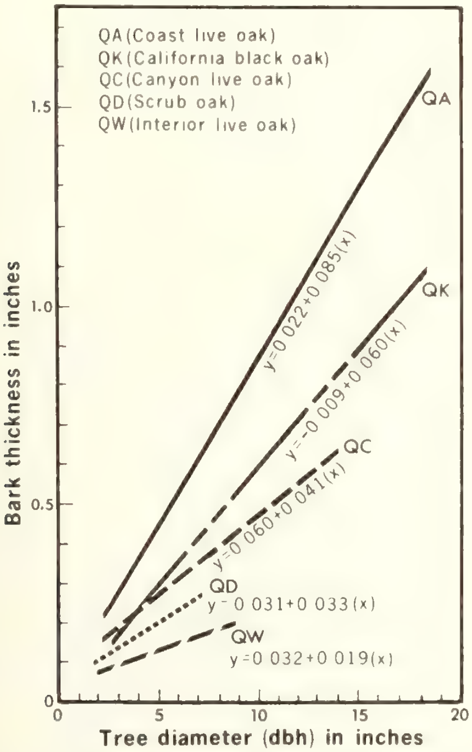

Figure 5--Total bark thickness of five southern California oak species was plotted in the range of d.b.h. classes sampled in the field. The curves are based on simple linear regressions determined by least squares.

The moisture content of bark varies from species to species, seasonally, and between the inner and outer bark (Vines 1968). The outer bark forms a sheath of low moisture content and low thermal conductivity around a zone of high moisture content and conductivity, the inner bark; however, the thermal diffusivity of both zones is similar (Martin 1963). Moisture contents I measured for coast and canyon live oak barks are as follows:

Species	Bark component	Percent moisture content
Coast live oak	Inner bark	106
	Wood	77
Canyon live oak	Flaky outer bark	11
	Inner bark	65
	Wood	60

These values are in line with other published data (Vines 1968, Martin 1963). The effect of moisture content on bark flammability may be more important than its effect on heat transfer (Gill and Ashton 1968).

The heat of combustion, the total amount of heat released during burning, for five southern California oaks is listed in table 2. With the exception of coast and interior live oak outer bark, all of the heat values are less than the theoretical 8600 Btu per pound. In each species, the inner bark has the lowest heat content, probably reflecting a low component of waxes and resins. The outer bark has the highest percent of acetone extractable materials (oil, fats, and resins), which accounts for its high heat content. Much of this potential energy is not released during normal burning conditions, however, because combustion is incomplete and some heat is used to vaporize moisture.

Bark density significantly affects the thermal properties of the bark; reported density values range from 17 to 39 lb/ft^3 for northeastern hardwoods and softwoods (Spalt and Reifsnyder 1962). Somewhat higher values were reported by Martin and Crist (1968). Based on a few observations, density values for five southern California oaks are listed in table 2. The outer bark of interior live oak at 61.3 lb/cu ft is very heavy and some pieces will sink in water. In contrast, the density of the flaky outer bark of canyon live oak is only about 31 lb/ft^3.

The thermal properties of bark--its insulating capacity--directly affect tree resistance to heat damage. Three such properties are described by Martin (1963):

1. Conductivity--the ability of a material to transmit heat through itself.

2. Specific heat--the ability of a material to absorb heat.

Table 2--Heat content and density of five southern California oak species (theoretical value for heat of combustion = 8600 Btu/lb)

Species and component	Density	Heat content[1]
	(lb/ft^3)	(Btu/lb)
Coast live oak		
Outer bark	64	9550
Inner bark	25	7675
Wood	39	7900
California black oak		
Outer bark	63	8025
Inner bark	64	6475
Wood	51	7900
Canyon live oak		
Flaky outer bark	41	7175
Outer bark	48	7525
Inner bark	43	6575
Wood	45	7875
Interior live oak		
Outer bark	62	9875
Inner bark	45	7700
Wood	44	7925
Scrub oak		
Flaky outer bark	37	8350
Outer bark	45	8250
Inner bark	63	6750
Wood	57	8060

[1] Values rounded off to nearest 25 Btu.

3. Diffusivity--the ratio of thermal conductivity to the product of specific heat and density.

Diffusivity is useful for evaluating the temperature change in a material over time, as in the cambium during exposure of the bark to fire. However, Martin found that the thermal diffusivity of bark is nearly constant over wide ranges of density, moisture content, and temperature (because of compensating effects) and is about one-fifth that of water.

TREE RESPONSE TO FIRE

In this section, the immediate and delayed response of the crown and trunk of a tree to fire are identified. Immediate tree effects range from no detectable damage to complete consumption or heavy charring, with tissue death. Delayed effects include sprouting from the tree base, trunk, and branches; cambial regeneration; and wood degradation by insects and disease.

Methods have been developed in the East for estimating, soon after a fire, the probable tree mortality, and for surviving trees, the probable wound size (Loomis 1973). Methods were also developed for predicting future sawtimber volume and quality loss, with dollar values (Loomis 1974). Procedures for predicting future amount of butt rot in fire-scarred red oaks in the South and ways to estimate extent of existing rot behind old scars are also available (Toole and Furnival 1957). Hepting (1941) gives a method for predicting future volume loss due to basal fire wounds, for Appalachian oaks. Similar studies have not been made in California. However, by applying results for oak in the East and South, we can obtain approximate damage estimates for the California oaks.

Estimating basal wound size and predicting tree mortality requires input about tree species, d.b.h., and the width and height of tree charring (Loomis 1973). Immediately after a fire, the width of a wound is fairly well approximated by the width of the charred area; however, wound height may exceed the charred area by several feet. The determination of char height is complicated by the deliquescent branching habit of some oaks; branching may begin almost at ground level.

Anticipated heart rot can be estimated for the present or predicted for the future using wound age and the ratio of wound width to tree diameter at stump height (Toole and Furnival 1957). Reported rates of spread range from 1.5 to 2.2 in. (3.8 to 5.5 cm) per year, with an overall average rate of upward spread of 1-1/4 ft (0.4 m) in 10 years.

Crown Damage

Crown damage can range from no effect to complete charring of the branches and total consumption of the leaves and small twigs. Often, different degrees of damage occur throughout a crown; the lowest part or the side facing an understory of brush or heavy fuel suffers greatest damage. If damage from a spring fire is limited to heat kill of the leaves, new leaves may emerge within a few weeks. Sprouting usually occurs also from the trunk and any branches that are not killed. Occasionally, some sprouts die back.

Basal Trunk Damage

The most common fire damage to a tree trunk is a basal wound caused by death of the cambium (fig. 6). Wounds less than a few inches across may eventually heal over with no accompanying heart rot (Toole and Furnival 1957), but larger wounds are responsible for the major loss of quality in eastern hardwoods. Establishment and spread of heart rot depends on many conditions, including resistance of the individual species, tree age, size of wound, and the species of fungus (Hepting 1941, Toole and Furnival 1957).

After a fire, a wound may also be attacked by various insects. As time goes by, new cambium may eventually cover a wound. However, if decay is active and wood of the wound face is destroyed, the growing cambium may curve inward and back on itself, forming a wound that may remain open for many years.

Subsequent fires may enlarge the wound until all that remains of the trunk is a thin, partial ring of mostly live wood. At this stage, the tree is a mechanical risk--subject to wind breakage. One more fire may so weaken the tree that it falls.

Heat damage to a zone of cambium completely around the trunk girdles a tree and eventually kills the crown. In a low intensity ground fire, cambium damage may be restricted to the lower 1 to 2 ft of the trunk however, with little or no immediate effect on the upper trunk or crown. I have seen trees girdled at this level still alive 8 years after the fire. The root system is probably kept alive by food supplied by the basal sprouts that develop after the fire.

How long the crowns of girdled trees will remain alive is not known. If the damaged zone is not too wide, the cambium may be able to reconnect. At any rate, trees with healthy-looking crowns, but with girdled trunks, may contribute to underestimation of fire damage.

RESPONSE OF SOUTHERN CALIFORNIA OAKS TO FIRE

Field evaluation of wildfire effects on five prominent southern California oak species began in 1974 to aid in postfire management planning. It was well known that most California oaks sprouted vigorously from the base when the trunk or crown, or both, were damaged; the study revealed important species differences.

On the site of the 1974 Soboba Fire, on the San Bernardino National Forest, almost 100 trees that had suffered damage ranging from light, spotty char to complete trunk and upper crown charring were selected, marked, and described. Postfire tree response (trunk and crown damage, resprouting, and death) was sampled for several years. Observations were made between 1975 to 1979 on seven other southern California National Forest areas burned by wildfire. Two areas burned by prescribed fire were also observed.

Permanent belt transects were selectively established in stands of coast live oak and California black oak on the Soboba Fire area, and in canyon live oak on the Village Fire area (Angeles National Forest). All trees in the transects were described by size, fire damage, and amount of postfire recovery. Follow-up sampling was done 1-1/2 to 2 years later.

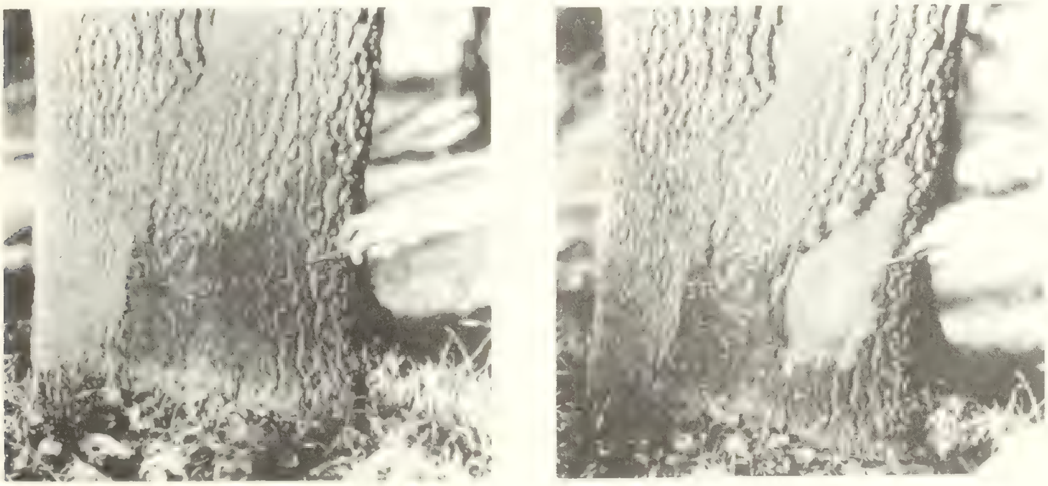

Figure 6--Basal trunk damage is the most common. Left, even a small charred area on a California black oak can indicate damage to the cambium; right, active cambium is rapidly growing over the wound.

Coast Live Oak

Coast live oak was studied on six burned areas. The Soboba Fire was extremely hot, and severely burnt several groves of coast live oak (table 3, fig. 7). A number of completely charred trees were examined about 5 weeks after the fire. Initial evidence indicated that the cambium of many of the trees was not killed, and proposed sale of several hundred of the large trees for firewood was canceled.

The preliminary survey revealed coast live oak's ability to resprout from both the trunk and branches. Heavily charred trees resprouted within a few weeks after the fire, and within 5 years, regrowth has filled out a good part of the preburn crown area (fig. 7).

A followup survey of 75 completely charred trees in July 1976, 23 months after the fire, showed that all trees less than 3 in. (7.6 cm) d.b.h. were top-killed, but 87 percent had basal sprouts. Most trees 3 to 6 in. d.b.h. were also top-killed, but about 20 percent had trunk or crown sprouts. None of the trees larger than 6 in. d.b.h. were dead, and at least part of the trunk and crown of 60 percent of the trees was still alive.

A subsequent tree survey on the Soboba Fire was run in June 1977 and May 1979, 34 and 57 months after the fire. All the trees in a belt transect 50 ft (15 m) wide and 565 ft (173 m) long were tagged and described. Data for the 57-month sample date (table 3) indicate that:

1. Only 4 percent of all the trees were completely killed by fire.

2. Ninety percent of the trees less than 3 in. d.b.h. were top-killed, but most had sprouted from the base, and only 2 percent were completely dead.

3. The trunks and crowns of all but 5 percent of the trees larger than 6 in. d.b.h. survived the fire, and only two of 111 trees were completely killed.

The ability of the upper crown of coast live oak to survive intense fires was observed on several other burned areas. Crown recovery was dramatic on all of these areas, although it appears that percent mortality is occasionally greater than that after the Soboba Fire. Sometimes, the trunk and branch sprouts of a coast live oak die back.

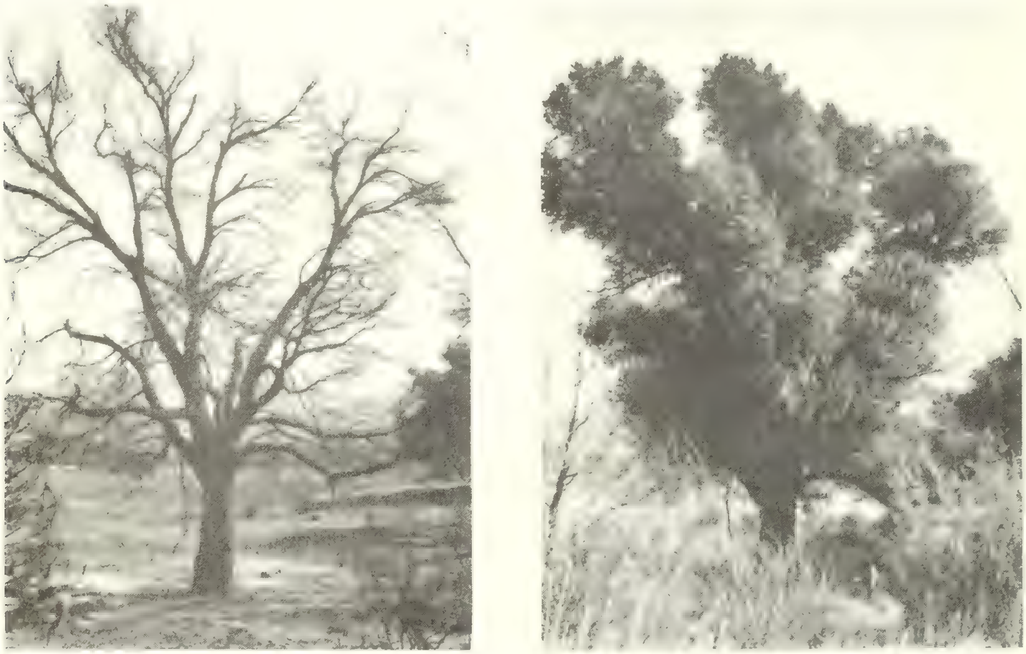

Figure 7--A tree may recover from extensive crown damage. Left, 3 weeks after a wildfire, a large coast live oak which was completely charred is sprouting along the tops of the lower branches; right, 5 years after the fire, a large part of the original crown has been replaced.

Table 3--Condition of coast live oak trees on the Soboba area about 5 years after being completely charred in an intense wildfire

Tree diameter (d.b.h., inches)	Number of charred trees, August 1974	Tree condition, May 1979			
		Dead	Basal sprouts only	Basal and crown sprouts	Crown sprouts only
		Percent			
0-3	90	2	88	1	9
3-6	54	11	26	28	35
6-12	65	1	5	52	42
12-18	24	0	0	62	38
18+	22	4	5	50	41

Other attributes than its outstanding fire resistance favor use of fire in management of coast live oak. The trees are often large, making prescribed fire for hazard reduction advisable; and the stands are often very dense, with a low fuel loading of shrubs and other flammable material.

California Black Oak

California black oak was studied on the Soboba site and on a site of the Vista Fire (San Bernardino National Forest) that occurred in 1972. A few trees in a small grove that suffered different degrees of fire damage were marked for study a short time after the 1974 Soboba Fire. The trunks and upper crowns of the trees on the perimeter of the stand were killed during the fire, but trees farther in the stand received proportionately less damage, although a few large, old, hollowed-out trees fell over.

In October 1978, a belt transect 25 ft (7.6 m) by 300 ft (92 m) was established in another grove which had been partially surrounded by heavy brush. All 72 trees in the sample strip were tagged and their condition recorded (table 4). Almost 5 years after the fire, only 9 trees were dead, and they were evenly distributed throughout the 6 to 18 in. (15 to 46 cm) size classes. Trees less than 6 in. d.b.h. had the lowest percentage of live crowns and highest percentage of basal sprouting.

A low intensity fire may kill the cambium of even very large California black oak trees where the trunk is charred (fig. 6). Because ground cover is usually sparse under stands of large trees with closed canopies, high intensity fires and complete girdling of the trees is not expected. The most severe damage to this species occurs on the stand periphery, where they are exposed to high temperatures from the surrounding brush.

The Cleveland National Forest successfully used prescribed burning for hazard reduction under California black oak in May and June 1978. An understory of green grass often prevented direct burning of the tree trunks. Although the leaves on some of these trees were heat killed, on most trees a crop of new leaves emerged 2 weeks later.

Canyon Live Oak

Fire effect on canyon live oak was first studied on the Soboba area; this work indicated that the trunk was relatively sensitive to heat damage. A more intensive investigation was made after the November 1975 Village Fire. The condition of 198 trees with partially live crowns in a belt transect 50 ft (15 m) wide and 565 ft (172 m) long was determined 18 and 36 months after the fire. Trees with girdled trunks and dead crowns were tallied, but not described.

The Village study site was in a dense, almost pure stand of canyon live oak. Most of the trees were between 6 and 12 in. d.b.h. Fire damage was generally restricted to charring of the basal 1 to 5 feet of the trunk, and leaf kill of one-third to two-thirds of the crown. The dead, flaky bark (fig. 4) often carried fire several feet up a trunk; leaves on branches a few feet from the ground were heat-killed, but not burned. It was common for the bark of any size tree to be completely burnt through, exposing the wood underneath. This is rare for the other species covered in this report.

Table 4--Condition of a stand of California black oak 50 months after the 1975 Soboba Fire

Tree diameter (d.b.h., inches)	Number of trees	Tree condition[1/]			
		Dead	Basal sprouting	Live crown[2/]	Basal sprouting + live crown
		Percent			
0-6	7	15	57	14	14
6-12	38	11	18	47	24
12-18	21	19	19	52	10
18-24	6	0	33	67	0

[1/] Initial fire damage ranged from no obvious effects to charring of the trunk and part of the crown.

[2/] Includes both undamaged crown and regrowth since the fire.

Eighteen months after the fire, all trees less than 3 in. d.b.h. were top-killed and 90 percent had resprouted from the base (table 5). Crown kill developed more slowly in the larger trees and 55 percent were still alive at 18 months, although most were thought to be completely girdled at the base. Because the tops of the trees were still green and growing, it appeared that they were healthy and had successfully survived the fire.

During the next 18 months, about one-half of the "live" crowns turned brown (table 6). Many of the remaining live crowns will probably die in the next 18 months. In general, canyon live oak trees that have complete basal char are probably girdled and eventually the crowns will die, although it may take several years.

The use of prescribed fire in the management of canyon live oak does not appear to be promising. The trees are too sensitive to trunk girdling. The flaky outer bark contributes to the fire, making even a low-intensity ground fire one of high intensity on the trunk surface. The rise of cambial temperature is probably directly related to the flammability of the outer bark (Gill and Ashton 1968). Prescribed fire might be safely used in a stand of very large trees where fuel loading is low or where the trunks are protected from direct heat damage.

Interior Live Oak

Postfire response of interior live oak was initially studied on the Soboba area, where several trees with different degrees of fire damage were monitored the first year after the 1974 fire. Interior live oak was more sensitive to fire than canyon live oak. Although the bark of these trees is mostly live and doesn't burn well, total bark thickness is not very great (fig. 5). In addition, most interior live oak trees in southern California are less than 12 in. d.b.h.; consequently, the bark offers very little protection.

The effect of fire on large interior live oak trees was observed in a recent survey on the Los Padres National Forest. Even trees with bark an inch or more thick were thought to be girdled at the base where the fire appeared to be of moderate intensity.

Successful use of prescribed fire in interior live oak management does not seem promising. Not only is the bark thin, it seems to be less heat resistant than coast live oak bark of equal thickness. Where the bark is charred, the cambium is almost certain to be killed. Protection of large, individual trees might be feasible on small areas.

Scrub Oak

Scrub oak (Q. dumosa Nutt.) was included in this report because it is an important component of the chaparral in southern California. Because of its small size and intimate association with highly flammable chaparral species, it is almost always top-killed by fire.

Table 5--Condition of canyon live oak trees 1-1/2 years after receiving basal trunk damage during the Village Fire, Angeles National Forest, 1975

Tree diameter (d.b.h., inches)	Number of trees	Tree condition			
		Apparently dead[1/]	Basal sprouting only	Basal sprouting + live crown	Live crown only
		Percent			
0-3	10	10	90	0	0
3-6	59	3	73	22	2
6-12	97	1	25	70	4

[1/] No evidence of live crown or sprouting.

Table 6--Decline over a 3-year period in the percent of live crowns of canyon live oak trees burned during the Village Fire, Angeles National Forest, 1975

Tree diameter (d.b.h., inches)	Trees with live crowns		
	Number of trees	After 18 months	After 36 months
		percent	
0-3	10	0	0
3-6	59	24	15
6-12	97	74	46

POSTFIRE MANAGEMENT PLANNING

The information reported here leads to some practical recommendations for postfire management planning. The decision to cut or not cut burnt trees as soon as a fire is out should be based on reliable information about anticipated tree survival. When possible, it is well to let at least one or preferably three growing seasons pass after a fire before making survival probability estimates and cutting decisions where survival is questionable.

The recommendations for cutting presented here (table 7) reflect only the expected response of trees to fire, and do not address other management considerations. The recommendations are generalized for size classes and degree of charring. Except in a crown fire, when direct effects tend to be the same on all trees, there is usually considerable range in degree of charring, and individual tree marking is appropriate.

The recommendation to cut assumes that a tree has been completely girdled and there is little or no chance for survival of the trunk and tree crown. The "leave" recommendation applies to trees in a range from those almost certain to survive to those which might survive.

Among trees that may survive are those which have basal wounds. A wound is usually limited to one side of a tree. I have seen tree crowns survive when less than 10 percent of the trunk circumference was left undamaged. Canyon live oaks 12 in. d.b.h. with wounds up to 20 ft (6.1 m) in height have remained completely functional. The question is, what percentage of a trunk circumference must be damaged before it should be cut? If a wound is narrow, the major portion of the trunk will remain intact, adequately supporting the crown of the tree. A prime consideration is whether or not the tree is presently or potentially a mechanical risk. As already noted, important wildlife, watershed, and recreation values will not be affected by serious trunk damage.

A tentative cutting guide might be:

1. Cut trees less than 6 in. d.b.h. that are more than 75 percent girdled.

2. Cut trees larger than 6 in. d.b.h. that are more than 50 percent girdled.

CONCLUSIONS

1. Oak species response to fire is variable. The trunk and upper crowns of coast live oak trees are highly resistant to fire kill and most trees resprout soon after they are burned. California black oak is less resistant to fire than coast live oak. Canyon

Table 7--Recommended guide to harvesting fire-damaged southern California oak trees, based on tree size and degree of trunk char[1]

Species	Less than 6 in. d.b.h.			6-12 in. d.b.h.			More than 12 in. d.b.h.		
	Light char	Medium char	Heavy char	Light char	Medium char	Heavy char	Light char	Medium char	Heavy char
Coast live oak	Lv	Lv	Cut	Lv	Lv	Lv	Lv	Lv	Lv
California black oak	Lv	Cut	Cut	Lv	Cut	Cut	Lv	Lv	Cut
Canyon live oak	Cut	Cut	Cut	Lv	Cut	Cut	Lv	Cut	Cut
Interior live oak	Cut	Cut	Cut	Lv	Cut	Cut	Lv	Cut	Cut
Scrub oak	Cut	Cut	Cut	Lv	Cut	Cut	[2]	---	---

[1] Assumes that 100 percent of the trunk circumference is affected, as follows: Light--spotty char or scorch, scattered pitting; Medium--continuous charring, scattered areas of minor reduction in bark thickness; Heavy--continuous charring and pronounced reduction in bark thickness, with wood sometimes exposed. Lv means that the tree should be left uncut for 3 years; Cut means the tree can be cut immediately.

[2] Scrub oak does not reach 12 in. d.b.h.

live oak, interior live oak, and scrub oak are more susceptible to fire damage than California black oak.

2. Large oak trees are generally more resistant to fire kill than small ones. Bark is generally thicker and crowns are higher above the ground--both features reduce vulnerability.

3. Bark thickness and composition vary considerably among the five oak species studied and appear to have a direct effect on fire damage to the cambium. Thick, live bark offers best protection; dead, flaky, outer bark may directly contribute to a tree's destruction.

4. Discolored inner bark and cambium, with an aroma of fermentation are the best indicators of tissue damage.

5. Oak response to wildfire is complex and depends on actions and interactions of many variables. Trees may not react as expected and without careful examination, sound or slightly damaged trees will be unnecessarily cut. Additional study of feasibility of prescribed burning in oak management is needed.

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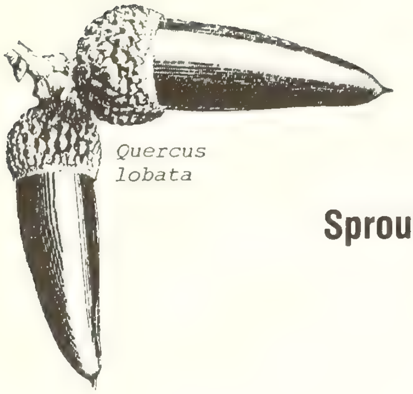

Sprouting in Fire-Damaged Valley Oaks, Chews Ridge, California[1]

James R. Griffin [2]

Abstract: Sprouting response of a total of 266 valley oaks was studied on plots representing three fire intensities in the Marble-Cone fire. In a crown fire plot all crowns were killed, but 53 pct of the roots survived to produce sprouts. After 1 year the crown fire plot sprouts averaged 59 cm in height. On a severe ground fire plot 82 pct of the oaks survived; 90 pct of the survivors had basal sprouts. Sprouts from trees with dead crowns emerged sooner and appeared more vigorous than sprouts from trees with live crowns. Mortality in a moderate ground fire plot was low; 57 pct of the survivors had basal sprouts. There was a trend in decreasing basal sprout vigor with increasing tree size. Ninety-three pct of the basally sprouting oaks had diameters between 10 and 39 cm.

INTRODUCTION

The Chews Ridge region in the Santa Lucia Range of Monterey County supports many age-classes of valley oak (Quercus lobata Née). Of particular interest are the younger trees, which are relatively well represented in this area (Griffin 1976). These small valley oaks are currently uncommon or rare in much of the oak woodland in California (Griffin 1977).

During the Marble-Cone fire of August 1977 all the valley oaks on the summit of Chews Ridge burned to some extent (Griffin 1978). Damage ranged from incineration by crown fire to light singeing by ground fire.

While surveying vegetation recovery on parts of the burn, I noticed younger valley oaks sprouting throughout the burned woodland on Chews Ridge. Knowing that few details of valley oak sprouting were recorded in the literature, I documented this interesting sprout situation where different age-classes had been subjected to various degrees of crown damage This report summarizes the sprouting response of over two hundred valley oaks during the first growing season after the fire.

LITERATURE REVIEW

It is common knowledge that most California oaks sprout when cut or burned. The shrubby oak species in the chaparral send up vigorous shoots after crown destruction, and the evergreen oak trees sprout actively from the base, sometimes from the crown as well. However, the deciduous white oak trees (valley oak; Oregon white oak, Q. garryana Dougl.; blue oak, Q. douglasii Hook. & Arn.) do not sprout as vigorously as the other California oaks. So little has been published specifically about valley oak that these two other closely related white oak trees are also reviewed here.

Jepson's (1910) early account of vegetative reproduction in white oaks remains the most helpful general reference. The following items are taken from his oak regeneration notes and individual species descriptions. All three species "stump-sprout" when young, but sprout vigor declines with age. Stumps of young white oaks are more likely to live than trees of the same size basally girdled and left standing. Oregon white oak may "weakly" stump-sprout in a few mature trees. Blue oak does not stump-sprout from mature trees, but it may "sucker" from the trunk if cut several feet from the ground. Unfortunately, Jepson gave no sizes or ages at which sprouting declined in these white oaks.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, Calif., June 26-28, 1979.

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Jepson stressed that natural valley oak regeneration is almost exlcusively by seed and that valley oak has the least vegetative reproductive potential of any California oak. He observed that: "Cutting off the trunk at the ground ends the life history at once, unless it be a small sapling-like tree. Increasing the height of the stump apparently makes no difference so long as the cut is below the first main arms or branches, but if the short stubs of the main branches be left then sprouting ensues freely."

I found no significant modern reference to valley oak sprouting. The wildlife habitat improvement literature has one item on how to encourage sprout production from blue oak stumps (Longhurst 1956). And the range improvement literature has a few notes on how to eliminate blue oak sprouts with herbicides (Leonard 1956, Leonard and Harvey 1956).

The few references mentioned above deal with the response of white oaks to mechanical or chemical crown damage. Even fewer references discuss sprouting induced by fire damage. Benson (1962) did speculate that blue oaks could not survive in chaparral habitats because of their relatively poor sprouting vigor. He stated: "Although the blue oak can survive grass fires beneath them in the oak woodland, they are killed outright by a hot brush fire, so they are unable to invade the chaparral." Benson was particularly contrasting savanna-grown blue oaks with white oak shrubs such as scrub oak (Q. dumosa Nutt.) which thrive in chaparral.

METHODS

I took general observations throughout a mosaic of fire damage conditions on Chews Ridge. The oaks inventoried for this report grew on the gentle summit between the U.S. Forest Service lookout tower and the Monterey Institute for Research in Astronomy site. This area was visited seven times between October 1977 and December 1978.

There was a general reduction in fire intensity across the study area. Regardless of location, however, each tree was classed individually into one of three damage groups on the basis of crown damage in 1977. "Crown fire" trees had all the leaves and smaller twigs consumed. The "severe ground fire" trees still had leaves, but the leaves were dead. In "moderate ground fire" areas some leaves in the upper crowns remained green. Most valley oaks in light ground fire areas had so little damage that they were not inventoried. Formal plot boundaries were not set, but the study area was essentially a complete sample of valley oaks on three plots totalling about 2 ha.

All the smaller valley oaks which might be able to sprout were marked with numbered aluminum tags nailed at dbh level on the north side of the trunk. The larger interspersed oaks were inventoried but not tagged unless they had damage features of special interest. For both tagged and untagged oaks, dbh, height of charred bark, condition of the 1977 leaves, condition of the 1978 crown, and size and nature of sprouts were recorded.

RESULTS AND DISCUSSION

Valley oaks are seldom subjected to as hot a fire as these received in the oak-pine woodland on Chews Ridge. This portion of the mountain last burned in 1928, so 49 years of fuel had accumulated. Although parts of the oak stands are still "savanna" with a ground cover of annual grasses or bracken (Pteridium aquilinum Kuhn), much of the area had been invaded by Coulter pines (Pinus coulteri D. Don) (Griffin 1976). These thickets of pine saplings and small trees with a deep litter of needles, branches, and cones greatly increased the fire hazard to the oaks. In addition, two consecutive drought seasons with only half of the expected precipitation added to the hazard.

From previous work I knew about several dozen large valley oaks, up to 206 cm dbh, that had been dead in the study area for some years. These snags were completely consumed during the fire. Only empty "root cavities" radiating out from large pits in the baked soil mark where the snags had been. Burning of these snags caused pockets of severe damage in otherwise moderate or light ground fire areas.

Crown Fire

The fire entered the southern end of the study area on August 12, 1977 after crowning uphill through chaparral and scrubby hardwood forest. Here the ground cover, shrub stratum, and tree leaves and small twigs were literally consumed. Trunks of the valley oaks, up to 22 m tall, were charred to their tops. Crowns of the oaks were completely killed; no epicormic sprouts appeared during the following year. Many of the rootsystems of the oaks were also killed. Crown fire mortality of valley oaks was 48 pct (Tables 1, 2).

The first basal sprouts I noticed on the

Table 1-- Diameter distribution of 53 valley oaks killed by three degrees of fire damage on the Chews Ridge study plots.

Dbh class (cm)	Crown fire	Severe ground fire	Moderate ground fire
0-9		1	
10-19	2	5	
20-29	2	8	2
30-39	3	3	
40-49	1		
50-59	4	1	
60-69	3		
70-79	5	1	
80-89	1		
90-99	3		
100-109	1	1	
110-119	1		
120-129	1		
130-139	1		
140-149			
150-159	1		1
160-169		1	
Total	29	21	3

Table 2-- Diameter distribution of 213 valley oaks with basal sprouts (B) and/or epicormic sprouts (E) within three fire damage classes on the Chews Ridge study plots.

Dbh class (cm)	Crown fire	Severe ground fire			Moderate ground fire		
	B	B	BE	E	B	BE	E
0-9	3						
10-19	15	32	4		9	6	3
20-29	9	32	7	4	2	13	9
30-39	2	10		4	2	12	7
40-49	1	4				1	2
50-59	1						4
60-69						2	
70-79							
80-89				1			3
90-99							2
100-109							2
110-119							2
120-129							1
130-139							1
140-149				1			
Total	31	78	11	10	13	34	36

study area were on these crown-fire-killed oaks. Within 60 days after the fire a few small valley oaks had basal sprouts up to 20 cm tall. These sprouts were already large enough to attract browsing deer. One year after the fire, heights of the browsed sprouts ranged from 15-120 cm with a mean of 59 cm.

Severe Ground Fire

When the fire moved onto the gentler slopes of the main summit, it no longer burned from crown to crown. Here the leaves were heat-killed but not burned. Any burning that did occur in the crowns centered around the dead wood exposed at broken limbs and tops of large trees. On trees with extensive internal rot, burning so weakened the trunks that the trees broke apart. In a few hollow trees the internal fires killed the trees while the bark remained unscorched. On small relatively thin-barked trees crown mortality resulted from heat-caused girdling through the bark. In many such trees the cambium died even though the bark was not charred.

Only 18 pct of the severe ground fire oaks died during the first year (Tables 1, 2). Of the surviving valley oaks 90 pct had basal sprouts (Table 2). After 1 year the browsed basal sprouts ranged in height from 10-115 cm with a mean of 47 cm. Twenty-one pct of the surviving valley oak trees had epicormic sprouts on trunks or large branches. At the end of the first year some epicormic sprouts were dying, and it was not clear how many of the old crowns would survive or be rejuvenated by these sprouts. Most of the small trees that do survive by epicormic sprouts will have serious basal fire scars; strips of bark were already peeling off where the cambium died by the end of the first year. The amount of fire scars on the thick-barked large survivors was not evident during the first year.

Moderate Ground Fire

Direct mortality from the fire was low in this area. Only two small trees and one large hollow tree out of 86 inventoried oaks died (Table 1, 2). Fifty-seven pct of the surviving valley oaks have basal sprouts (Table 2). One year after the burn the browsed basal sprouts ranged in height from 10-120 cm with a mean of 45 cm. All trees with live crowns had some degree of epicormic sprouting in the lower crown. One year after the fire the large oaks had relatively normal-looking crowns. The small trees had mixtures of dead leaves, epicormic sprouts, and normal twigs. Many of the small trees will have basal fire scars.

Sprout Vigor

The dbh distributions in Table 2 strongly support Jepson's (1910) generality that valley oak sprouting vigor declines with age. The largest tree to have basal sprouts was 66 cm dbh, and 93 pct of the trees with basal sprouts were between 10 and 39 cm dbh.

Basal sprout heights could not be determined very precisely. The tips of some froze early in the season, and almost all sprouts suffered some die-back from mildew infection. In 1978 mildew was abundant on sprouts of all oak species over the entire Marble-Cone burn. Black-tailed deer added even more problems in measuring sprouts, for over 90 pct of the sprouts had been browsed.

I did not correlate sprout height with dbh, but smaller trees appeared to have larger sprouts. The modal height class for basal sprouts was 40-59 cm. Of the 27 sprouts that were 70 cm or more tall only three were from trees greater than 25 cm dbh. Regardless of size, valley oaks with dead crowns appear to sprout earlier, have longer sprouts, and produce more sprouts per trunk base than trees with live crowns.

Fire Control Implications

Apparently the Marble-Cone fire caused a rather high number of valley oaks to sprout. Even if heavy sprout mortality occurs in the next few years, an obvious number of sapling sprout clumps should develop. This amount of basal sprouting has not occurred after previous fires on Chews Ridge. The 1928 fire produced few if any successful sprout clumps on the study area. Pre-1928 fires caused only 3 pct of the stand to sprout; the 266 trees inventoried contained only eight sprout pairs and one sprout trio. Past fires also left basal fire scars on only 4 pct of the valley oaks on the study area.

Since the least sprouting after the Marble-Cone fire occurred in areas with no more than moderate ground fires, this study suggests that Chews Ridge did not have widespread crown or severe ground fires during the establishment of the present valley oak stands. Burns as serious as the Marble-Cone fire in the past should have caused a higher proportion of valley oak sprout clumps and more conspicuous basal fire scars on the surviving valley oaks.

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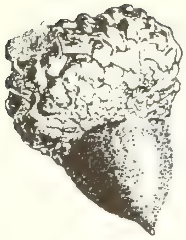

Effect of Chronic Oxidant Air Pollution Exposure on California Black Oak in the San Bernardino Mountains[1]

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and Maureen A. Thomas[6]

Abstract: The effects of ambient oxidant air pollution exposure between 1974 and 1978 on California black oak (Quercus Kelloggi Newb.) leaf injury development, stem diameter growth, acorn production, and relationships to insect pests and disease were studied in 15 vegetation plots located along a gradient of decreasing oxidant dose in the San Bernardino Mountains of southern California. Leaf injury decreased uniformly along the decreasing dose gradient. Year-to-year observations suggested that greater leaf injury was related to lower air temperatures, concurrent with cumulative dose and higher precipitation during the preceding winter and spring. Greater leaf injury generally resulted in lower average stem diameter increases between 1975 and 1978 when the total tree population was considered; however, site quality obscured this difference in some plot comparisons. Distribution of the insect and disease complex did not appear related to the oxidant stress gradient; however, the fruit tree leaf roller and oxidant injury acted additively to injure foliage at several plots. Acorn production appeared depressed at these sites. The results of this study suggest that black oak will continue to show diminished productivity if ambient oxidant air pollution remains at levels measured in recent years.

INTRODUCTION

California black oak (Quercus Kelloggi Newb.) is an important species in the mixed-conifer and pine types of the San Bernardino Mountains. It is found in stands dominated by either ponderosa pine (Pinus ponderosa Laws.) or Jeffrey pine (P. Jeffreyi Grev and Balf.). The seedling density of associated conifers, namely ponderosa pine and white fir (Abies concolor, [Gord. and Glend.] Lindl.), is positively correlated with black oak crown cover in the San Bernardino Mountains (McBride 1978a) and the oxidant damaged ponderosa pine-black oak type appears to be shifting towards a blac oak type (McBride 1978b). Since 1974, data have been collected on a gradient of decreasing oxidant dose in the San Bernardino mountains (Miller and others, 1977).

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This report describes preliminary results of work on the relationships of within-season and end-of-season leaf injury in black oak and radial growth to oxidant dose and weather variables. The frequency of acorn crops and the activity of defoliator insects and diseases along the oxidant gradients are also reported.

METHODS AND MATERIALS

Study Sites

Fifteen permanent plots were established in an east to west direction, from 1515 to 2212 meters elevation, in the San Bernardino Mountains. Resultant plot locations corresponded to a gradient of decreasing oxidant air pollution effect, with increasing distance to the east. The oxidant gradient occurred within a 44.4 kilometer span between Camp Paivika at the extreme west and Camp Osceloa at the extreme east. Another dimension of the gradient was related to the south-to-north separation of plots, for example, the 3 to 4 kilometer span between Sky Forest on the rim overlooking the basin and the University of California Conference Center on the north shore of Lake Arrowhead. Plots were listed in order of ascending elevation, with distances and azimuths from Camp Paivika, the number of California black oak trees, and the principal pine associated in each plot (table 1).

Plots were selected on the basis of relative homogeneity of tree cover. They were generally located on flat terrain or gently sloping north aspects. Plot width was always 30 meters but length varied depending on the distance required to obtain the 50 ponderosa (PP) or Jeffrey (PJ) pines equal to or greater than 30 centimeter diameter breast height (d.b.h.). All tree species equal to or larger than 10 centimeter d.b.h. were labeled with numbered metal tags.

Oxidant Monitoring and Meteorological Measurements

Hourly ozone measurements were obtained from May through September, beginning in 1974, at three permanent stations--Camp Paivika, Sky Forest, and Barton Flats. The

Table 1--Permanent plot characteristics with plots listed in order of increasing distance from the Camp Paivika plot.

Plot name	Abbreviation	Elevation and pine[1] associate(s)	Location relative to Camp Paivika		Black oak trees
			Distance	Azimuth	
		meters	kilometers	degrees	
Camp Paivika	CP	1587 PP	---	---	63
Breezy Point	BP	1515 PP	2.8	19	31
Tunnel Two	TUN2	1642 PP	9.6	75	20
Dogwood A	DWA	1715 PP	11.0	92	16
Univ. Conf. Cen.	UCC	1600 PP	13.3	77	13
Sky Forest	SF	1709 PP	13.4	92	7
Camp Oongo	COO	1891 PP	18.3	94	33
Green Valley Cr.	GVC	1939 PP,PJ	21.8	92	73
Deer Lick	DL	1891 PP,PJ	23.3	100	38
Snow Valley 1	SV1	2060 PJ	26.7	94	16
Camp Angelus	CA	1818 PP	34.1	107	19
Schneider Cr.	SCR	1842 PP	36.0	105	33
Barton Flats	BF	1891 PP,PJ	40.4	101	13
Holcomb Valley	HV	2212 PJ	40.8	82	4
Camp Osceola	CAO	2121 PP,PJ	44.4	101	14

[1] pp = ponderosa pine; JP = Jeffrey pine

DASIBI ultraviolet photometers used at these stations were calibrated by the California Air Resources Board in El Monte. Data were recorded on strip charts. Mast total oxidant meters (the instrument signal includes over 90 percent ozone and small amounts of NO_2 and peroxyacetyl nitrate) were used at all sites prior to 1974; during the 1974 to 1978 period they were located for two to three week periods at or nearby each vegetation plot. These temporary plot measurements were compared hourly by regression with the nearest of the three permanent stations so that missing hourly concentrations could be calculated.

Mast meters were calibrated against a DASIBI ozone photometer that was maintained in the laboratory as a transfer standard. Power was provided for Mast meters at plots with four 6 volt, 217 A/hr lead acid batteries that were replaced with newly charged batteries twice per week. DC to AC inverters were required. The Datamart strip chart recorders used at plots had self-contained rechargeable gel cell batteries.

All oxidant and ozone data were adjusted for the elevation difference between the calibration site and each mountain station or plot location by a factor ranging from 1.16 at 1515 meters to 1.26 at 2212 meters. Cumulative ozone or oxidant dose was obtained by summing all hourly concentrations equal to or greater than 0.03 ppm.(the natural background concentration).

Air temperature and relative humidity were measured hourly at the three permanent stations and telemetered by radio or telephone line to the laboratory in Riverside. The system was designed by Ball Brothers Research, Boulder, Colorado. At remote vegetation plots, temperature and relative humidity were measured with hygrothermographs in standard weather instrument shelters.

Winter precipitation was collected at vegetation plots using "Sacramento" storage gauges standing 147 centimeters high, with a 48 centimeter diamter base, and a 25 centimeter diameter orifice. The gauge was charged with antifreeze and a thin surface layer of automatic transmission fluid. Accumulations were measured monthly, when possible. Standard rain gauges and, later, a modification of the snow gauge were used to collect summer precipitation. The modification consisted of a 23 centimeter diameter funnel and collection bottle inserted into the orifice of the snow gauge.

Observation of Black Oak Responses

Oxidant Injury--At two week intervals, starting in mid-June and ending by early September, within season measurement of leaf injury was evaluated at 5 of the 15 plots. Three branch tips were permanently tagged on each of five trees per plot; this labeling provided assurance that the same leaves would be observed each time. A five-category descriptive scale was used to evaluate the symptom intensity represented by the aggregate of leaves on each branch tip:

Scale	Description
4	Leaves completely green
3	First evidence of interveinal chlorosis, chlorotic mottle, or necrotic lesions mainly on upper surfaces
2	Moderate levels of interveinal chlorosis, chlorotic mottle, necrosis mainly on the upper surface
1	More severe than category 2 with necrosis extending to the lower leaf surface
0	Leaves necrotic on both surfaces

An end-of-season evaluation of chronic leaf injury was made of all black oaks at each of the 15 plots, during the first 10 days of September, each year from 1974 to 1978. About half the plots were not visited in 1977 due to scheduling problems. In this procedure the leaf canopy of each tree was arbitrarily divided into upper and lower halves and leaf condition was described separately usually through wide-angle binoculars. Year-to-year comparisons are thought of as relative levels of deterioration from the healthy, symptomless score of 8 (4 each for upper and lower canopy).

Stem Growth and Acorn Crops--In 1975, a nail was placed at 1.4 meters d.b.h. on all trees. In 1978, the d.b.h. was remeasured. The diameter growth difference between the autumns of 1975 and 1978 (three growing seasons) was compared from plot to plot and for all plots, with particular attention to the relationship between growth and leaf injury.

Both the upper and lower crowns of each tree were inspected for acorns during end-of-season observations. The frequency of acorn crops for each tree was compared for the 1973-1978 period.

Insect Activity, Diseases, and Other Environmental Stresses--At two plots, namely CP and BP, black oaks were infested with the fruit tree leaf roller (*Archips argyrospilus* Walker) throughout the study period (Brown and Eads 1965). Eight other plots had minor infestations for at least 1 year. Some of this early summer defoliation was possibly due to the California oak moth (*Phryganidia californica* Packard). The resultant defoliation was described as 1, light; 2, moderate; and 3, severe. Defoliation at the end of the season was comprised of a new flush of leaves that were produced following the activity of the insects in May and June.

True mistletoe (*Phoradendron flavescens* var. *villosum* Nutt. Engelm. in Rothr.) was observed and recorded as one of three intensity levels, depending on the number of mistletoe plants, their position on the tree, and amount of mistletoe-caused branch mortality.

Stem decay was recorded only when indicated by external evidence. A dieback of oak branches was observed and recorded as one of three intensity levels, depending on the number of branches affected. Limb and main stem breakage traceable to excessive snow loading and loss of trees due to firewood collection were recorded.

RESULTS

Responses to Chronic Oxidant Exposure

Initial Screening of Data--The Kruskall-Wallis nonparametric test showed that oxidant-caused leaf injury, fall and spring precipitation, and acorn production all differed beyond chance from plot to plot. The results of other analysis methods follow.

Relationship of Leaf Injury and Plot Location--The influence of distance from west to east and plot elevation was recorded for black oak leaf injury each season from 1974 to 1978 (fig. 1). The plots are shown in relation to elevation and distance from CP. The influence of distance from the pollutant source is most evident for those plots 40 to 44 kilometers east of CP and above 2000 meters elevation, where average leaf injury for each of the 5 years at BF, CAO, SV1 and HV was $\geq$ 7.0 (very slight to no injury).

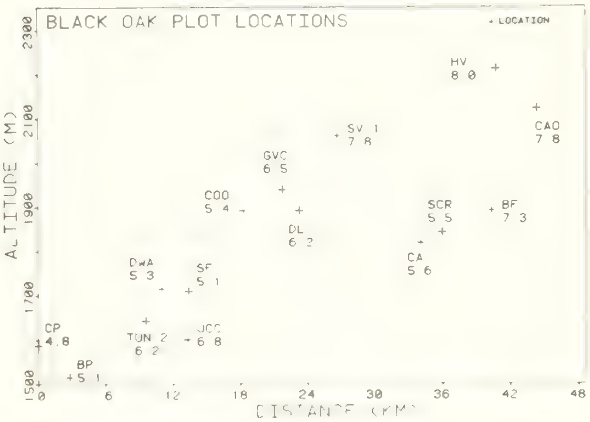

Figure 1. Average leaf injury score for the end of each season from 1974 to 1978 for black oaks in plots located on an elevational and a west-to-east gradient of decreasing oxidant dose in the San Bernardino Mountains. A score of 8.0 means no injury.

The five plots with the greatest average leaf injury (CP, BP, SF, DWA and COO) are all within 18.5 kilometers of the extreme west end of the study area. The elevations of these stations range from 1515 to 1891 meters. Average leaf injury in these plots was moderate, ranging between 4.8 and 5.4.

Relationship of Stem Diameter Growth to Plot Location and Leaf Injury--A comparison of the plot rankings for leaf injury and growth shows generally poor correspondence (table 2). For example, black oaks at SF and DWA show larger growth increases in spite of moderate leaf injury. Another comparison shows good growth responses at TUN2 and UCC when the average leaf injury was only slight, but these plots are considered to be in a high oxidant dose area (9.6 and 13.3 kilometers, respectively, from CP and 2.5 to 3.0 north of the ridgecrest overlooking the polluted basin). The smaller diameter increases at CP and BP compare well

Table 2--Average leaf injury scores from 1974 to 1978 and stem diameter increase between 1975 and 1978 at the 15 permanent plots in the San Bernardino Mountains.

Plots in order of decreasing leaf injury	Distance from CP	Average leaf injury[1/] (1974-1978)	Diameter increase (1975-1978)
	kilometer		centimeter
CP	----	4.8	0.61
BP	2.8	5.1	0.68
SF	13.4	5.1	1.27
DWA	11.0	5.3	1.51
COO	18.3	5.4	1.00
SCR	36.0	5.5	0.82
CA	34.1	5.6	1.26
TUN2	9.6	6.2	1.15
DL	23.3	6.2	0.50
GVC	21.8	6.5	1.04
UCC	13.3	6.8	1.50
BF	40.4	7.3	1.16
CAO	44.4	7.6	0.65
SV1	26.7	7.8	ND
HV	40.8	8.0	0.78

[1/] 0 - 1.99	Very severe
2 - 3.99	Severe
4 - 5.99	Moderate
6 - 7.99	Very slight to slight
8	None

with greater leaf injury, but chronic defoliation of many trees by the fruit tree leaf roller at these plots may be partially responsible for the smaller growth response.

To further explore the effect of leaf injury on growth, a regression was fitted for each plot but the R^2 values did not exceed 0.15. An analysis of variance was used to test the regressions of growth on injury for all plots, showing that slopes and intercepts differ beyond chance from plot to plot. The importance of plot (as expressed through characteristics like soil depth, water holding capacity, and slope) on average radial growth is reported by Gemmill in this volume.

The influence of leaf injury on stem growth was examined by comparing four samples from the total population (table 3). Plot characteristics seem to dominate as the most important variables associated with stem growth; however, another method was used to investigate the relationship of leaf injury and growth in which the total tree population was examined without respect to plot characteristics. The total tree population was divided into four stratifications, or leaf injury categories, so that the growth responses of each grouping could be tested using the two-sample t-test for unequal sample sizes. The test results show substantial differences where the p values were 0.000 for the first three groupings and 0.004 (separate) and .002 (paired) for the fourth, namely, 0-6.99 vs 7.0-8.0.

The growth differences, evident from these comparisons based on leaf injury, are greatest when the 0-3.99 categories are compared with the larger group of trees with less leaf injury. The growth difference becomes smallest when trees in the 7.0-8.0 leaf injury category are compared with the remaining population.

On the basis of leaf injury observations at six plots experiencing the heaviest oxidant doses (CP, BP, TUN2, DWA, SF, and COO) only 12 out of 170 trees in these plots could be considred oxidant tolerant, that is, with a 7.0-8.0 injury score average for the 1973-1978 period.

Table 3--Growth of four black oak samples from the total population when stratified by leaf injury category.

Leaf injury categories compared	Trees per category	Average diameter increase[1] (1975-1978)	Differences between categories
		centimeter	centimeter
0 - 3.99 vs	29	0.41 ± 0.13	
4.0 - 8.0	349	0.95 ± 0.07	0.54
0 - 4.99 vs	95	0.63 ± 0.09	
5.0 - 8.0	283	1.00 ± 0.07	0.37
0 - 5.99 vs	188	0.75 ± 0.08	
6.0 - 8.0	190	1.05 ± 0.09	0.30
0 - 6.99 vs	279	0.84 ± 0.07	
7.0 - 8.0	99	1.07 ± 0.14	0.23

[1] Confidence interval of 95 percent

Examination of Conditions Affecting Leaf Injury Development--Six of the plots receiving the greatest chronic exposure were compared for year-to-year variation of average leaf injury for the 1974 to 1978 period (table 4). Five of the plots (CP, BP, DWA, SF and COO) had similar leaf injury for each year over the 5-year period. These plots are located on the ridgecrest overlooking the polluted urban basin. TUN2 may have had less injury because of the pollutant dilution resulting from its location

Table 4--Annual leaf injury to black oaks at six plots located within an 18 kilometer-long by 4 kilometer-wide zone at the heavily polluted western end of the San Bernardino Mountains.

Year	Plot						Avg[1,2]
	CP	BP	TUN2	DWA	SF	COO	
	Average leaf injury score						
1974	5.5	5.6	6.9	5.1	5.4	5.5	5.4±0.15
1975	5.5	5.2	5.7	5.4	4.9	5.5	5.2±0.15
1976	4.7	4.3	6.0	4.6	4.3	4.7	4.6±0.15
1977	6.5	6.3	6.9	6.4	6.1	6.5	6.2±0.15
1978	4.6	4.1	5.6	5.0	5.0	4.6	4.6±0.15
Ave:	4.8±0.11	5.1±0.16	6.2±0.20	5.3±0.22	5.2±0.34	5.4±0.11	5.2±0.06

[1] Average injury for a single year for trees at the six plots could not be derived from averaging the six individual values for that year because plots must have the same number of trees

[2] Confidence interval of 95%

2.6 kilometers north of the first ridgecrest. The average injury at all plots varied similarly from year to year. The most severe injury occurred in 1976 and 1978; 1977 had the least injury, while 1974 and 1975 were intermediate. The data required to examine the different variables associated with symptom development at all six plots is not yet available for all years.

Sufficient data was available at plot DWA to examine year-to-year changes of leaf injury. These data show the relationships of cumulative oxidant dose and other variables to injury, for the years 1976, 1977 and 1978. During these years, injury development was measured biweekly throughout the growing season. The data suggest that the larger amounts of injury in 1976 and 1978 are associated with lower mean hourly June-September air temperatures and moderate to high total seasonal precipitation (starting in October of the preceding year) (table 5). The correlation between cumulative oxidant dose and within-season development of leaf injury is greatest in 1978. The negative correlation in 1977, when the dose was only slightly less than in 1978, coincides with lower precipitation and a higher mean seasonal temperature. These preliminary results suggest the hypothesis that higher temperatures coupled with lower soil moisture availability are expressed as lower daytime tree water potentials that, in turn, limit both transpiration and pollutant uptake.

Frequency of Acorn Crops--The number of trees producing acorn crops during the 1974 to 1978 period were compared listing plots in order of decreasing leaf injury. The year of peak production was 1977, followed by 1978. The general impression is that trees with less leaf injury and more rapid growth also produce more acorns (table 6). The small number of acorn bearing trees at CP and BP may result from the combination of stresses imposed by oxidant pollution and the fruit tree leaf roller. The locations where trees produced more acorn crops during the five-year period than the number of trees in the plot were DWA, TUN2, GVC, BF and SV1. In some cases, this resulted from the same tree producing acorns in successive or alternate years. The average diameter increases at these plots were all among the highest, as seen from ranking of plots in the column on the far right in table 6.

Diseases and Insect Pests of Black Oak Experiencing Chronic Oxidant Stress

The pest complex present on black oaks was described for each of the 15 plots in order of decreasing leaf injury (table 7). During the 5 year observation period only six of the original 428 trees in all the plots died due to pests or physical damage, and six were removed for firewood. The two most prevalent problems were insect defoliators (primarily the fruit tree leaf roller) present on 40 percent of the plot trees for one or more years and a branch girdling canker observed on 24 percent of the trees. The fungal cause of the canker has not been determined. The fruit tree leaf roller has been present in the western portion of the San Bernardino Mountains for at least 10 to 15 years prior to our observations.
The canker dieback was very scarce in the four plots experiencing the most oxidant-caused leaf injury. No evidence exists to suggest that the distributions of either the

Table 5--Variables that may have interacted to control leaf injury development of black oak at the DWA plot in 1976, 1977, and 1978.

Year	End of season leaf injury	Cumulative seasonal oxidant dose	Correlation of dose and within-season injury	Precipitation, Oct.-Sept.	Average air temp. June-Sept.
		(ppm-hr)		(cm)	(C)
1976	4.6	151.3	+ 0.40	89.1	15.5
1977	6.4	160.3	- 0.27	73.8	18.4
1978	5.0	168.4	+ 0.66	155.9	16.1

Table 6--Trees producing acorn crops between 1974 and 1978 (plots listed in order of decreasing leaf injury).

Plot name	Total trees per plot producing acorn crops 1974 - 1978		Trees with acorns each year					Plots in order of increasing diameter growth
	Acorn crops	Trees	1974	1975	1976	[1/]1977	1978	
CP	11	66	7	3	1	0	0	DL
BP	3	31	3	0	0	0	0	CP
SF	5	7	1	1	1	1	1	CAO
DWA	18	16	5	9	2	2	0	BP
COO	27	39	2	0	1	19	5	HV
SCR	17	37	2	7	6	2	0	SCR
CA	10	20	2	7	0	1	0	COO
TUN2	22	20	7	10	0	1	4	GVC
DL	28	41	ND	ND	2	20	6	TUN2
GVC	115	82	0	0	9	66	40	BF
UCC	4	13	1	3	0	0	0	CA
BF	22	16	1	1	7	13	0	SF
CAO	10	16	0	0	3	7	0	UCC
SV1	28	16	1	0	6	12	9	DWA
HV	4	6	0	0	1	2	1	(SV1=ND)
Total	324	426	32	41	39	146	66	
Percent	76.0		7.5	9.6	9.1	34.3	15.4	

[1/] The 1977 data for GVC, DL, HV, CA, SCR, BF and CAO were contributed by Robert F. Luck, Division of Biological Control, University of California, Riverside

defoliator or the branch canker are influenced by oxidant stress. These agents more likely are to be controlled by existing air temperature or soil moisture gradients.

True mistletoe infections were present at only five plots, the most severe problem being at SCR. No direct effects of oxidant were recognizable on the mistletoe foliage and no observations were made of mistletoe fruiting.

Stem decay was detectable on only 2 percent of the trees, mainly those of large diameter. The actual incidence of decay would probably be higher under a more thorough examination.

In spring 1974, a heavy snow caused a small amount of upper stem and branch breakage. The utilization of study plot trees is indicated by the numbers removed for firewood by 1978; one or two were living at the time of removal.

The relatively small size and small number of plots did not provide an optimal design for the best estimate of pest activity over the complete study area. The intensity levels (1, 2, and 3) to describe the defoliator, canker dieback, and true mistletoe severity on each tree provide a useful estimate of the severity of infestations or infections.

DISCUSSION

This study was part of an interdisciplinary study to predict successional trends in forest stands subjected to several chronic oxidant dose levels (Miller and others 1977). The trend in observed amounts of oxidant-caused leaf injury corresponded to the injury to oxidant-sensitive conifer species in the same plots oriented generally along a gradient of decreasing cumulative

Table 7--Pest complex and other environmental factors affecting black oaks in the San Bernardino Mountains, 1974 to 1978.

Plot name	Trees 1974	Dead trees in 1978	Insect defoliators[1/]			Canker dieback			True mistletoe			Stem decay	Snow damage	Taken for firewood
			1	2	3	1	2	3	1	2	3			
CP	69	2	2	37	28				1				1	1
BP	31	0	5	9	17				2					
SF	7	0			2	1								
DWA	16	0	7											
COO	39	0	22	1		7	3	1					2	
SCR	37	3	16			15	6	1	9	1	3	3		
CA	20	1	16			6			1	1	1	2		1
TUN2	20	0	4			3				2	1			
DL	40	2	1			15	3					1		2
GVC	82	3				18	1	1				1	2	1
UCC	13	0												
BF	16	1				6	1	1				1	2	1
CAO	16	0	4			6	3						3	
SV1	16	0				2								
HV	6	0				2								
Total	428	12	77	47	47	81	18	3	13	4	6	8	10	6
Partial percent		2.8	18.0	11.0	11.0	18.9	4.2	0.7	3.0	0.9	1.4	2.1	2.1	1.1
Percent			40.0			23.8			5.3					

[1/]
1. Light
2. Moderate
3. Severe

seasonal dose. Oak leaf injury varied from year to year; a high cumulative oxidant dose, moderate to high precipitation of the preceding winter and spring, and low to moderate air temperature stress concurrent with oxidant exposure during June-August appeared to cause greater injury. Cumulative oxidant dose and the June-August transpiration pattern must be evaluated together in order to develop a dose response simulation.

Tests of the relationship between average leaf injury during 1974-1978 for all trees in a plot and average diameter increase during 1975-1978 were inconclusive when plot comparisons were made. The variations of site index for black oak, as defined by Powers (1972), appeared to obscure comparisons of leaf injury on growth because intercepts were higher on the better sites; however, conclusive effects of leaf injury on growth were observed when the populations from all plots were pooled and, in effect, the influence of site index was averaged for 14 plots. The magnitude of this growth decrease relative to companion species in the stand will be determined after further data analysis is completed. McBride (1978b) has suggested a shift toward black oak in the oxidant stressed ponderosa pine-black oak type indicating that ponderosa pine experiences a larger decrease in growth and competitive ability. But, when oxidant stressed oaks are present on poor sites or when the effects of defoliator insects and pathogens are coupled with oxidant injury for several decades some weakened trees may succumb to these combined stresses. This condition could develop in the stands at the CP and BP plots; chaparral shrubs or grasses may eventually be the dominant cover type in this worst case situation.

Acorn production was very low at CP and BP during the study period. Thus, the combination of oxidant injury and defoliation by the fruit tree leaf roller may have an additive influence on both growth and reproduction.

The number of trees producing acorns peaked in 1977, when all plots were considered. Roy (1962) reported that abundant acorn crops for entire stands occurred every 2 to 3 years, but our data suggest a longer interval in the study area. A more detailed analysis of the size and frequency of acorn crops is being done by Robert F. Luck, the principal investigator for this phase of the interdisciplinary study.

The distributions of two other diseases, namely a branch dieback apparently caused by a fungus (not identified) and true mistletoe, do not appear related to the severity of oxidant stress. Their distribution appears to be related to stand conditions and temperature-and-moisture gradients that existed prior to oxidant stress. The possible role of peroxyacetyl nitrate (PAN), a companion with ozone in the photochemical oxidant complex, has not been defined. At this time, it is not unreasonable to assume that ozone is the principal cause of the kinds of leaf injury symptoms observed.

McDonald (1969) described the resource values of black oak as a major component of six forest types in California and Oregon. Powers (1972) emphasized the economic potential of the species. These descriptions provide a perspective from which it is possible to conclude that chronic oxidant air pollution injury can have significant primary and secondary effects on black oak and the forest ecosystems of which it is a component.

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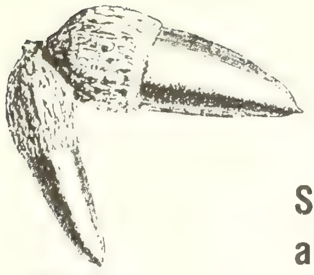

Quercus agrifolia

Sea-Salt Aerosol Damage to *Quercus agrifolia* and *Quercus lobata* in the Santa Ynez Valley, California[1]

Gary L. Ogden[2]

Abstract: This is a physiological ecology paper demonstrating the effect of far inland advection of sea salt aerosol on leaf damage symptoms and asymmetrical growth forms of two oak species (Quercus lobata, Quercus agrifolia) in a coastal valley in California. Foliar absorption of aerosol (chloride ion) produces leaf damage symptoms and asymmetrical growth forms on oaks up to 60 km inland under normal climatic conditions. Leaf morphological characteristics and environmental factors which cause a differential rate of Cl^- foliar absorption by oak foliage is discussed.

INTRODUCTION

The study area is located in Southern California in the Santa Ynez Valley. The W-E orientation, mountain enclosure, and gradual increase in elevation from the ocean inland make it an ideal area for aerosol advection studies. The 2 principal oak species occurring on the alluvial flats and gentle slopes (Q. agrifolia and Q. lobata) have overlapping distributions and differing growth forms (fig. 1).

Quercus agrifolia at a distance of 5.6 km inland is a prostrate pruned shrub approximately 1.8 m in height. The shrub is flagged from west to east. The trunks lean away from the ocean. At 7.2 km inland Quercus agrifolia is more arborescent, ranging up to 3.6 m in height but still flagged away from the ocean. At 16.1 km inland Quercus agrifolia is a leaning single-trunked tree, with the angle of lean less severe than at more coastal sites. At 28.2 km, this species exhibits no lean and stands as a single-trunked specimen.

Quercus lobata is only found 28.2 km or at greater distances from the coastline at Surf. Here, it takes on a pruned form with a severely leaning trunk. It resembles the form of Quercus agrifolia at the 16.1 km site. Quercus lobata still shows a flagged appearance at 48.3 km inland, but the severity of lean is less than at the 28.2 km site. Both oak species grow normally at distances of 72.4 km inland.

These observations suggest that either the wind or something in the wind is causing the differential growth form of the two oak species. Wind dessication could cause an asymmetrical growth due to differential killing of buds and leaves on the windward (west

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Scripps College, Claremont, California, June 26-28, 1979.

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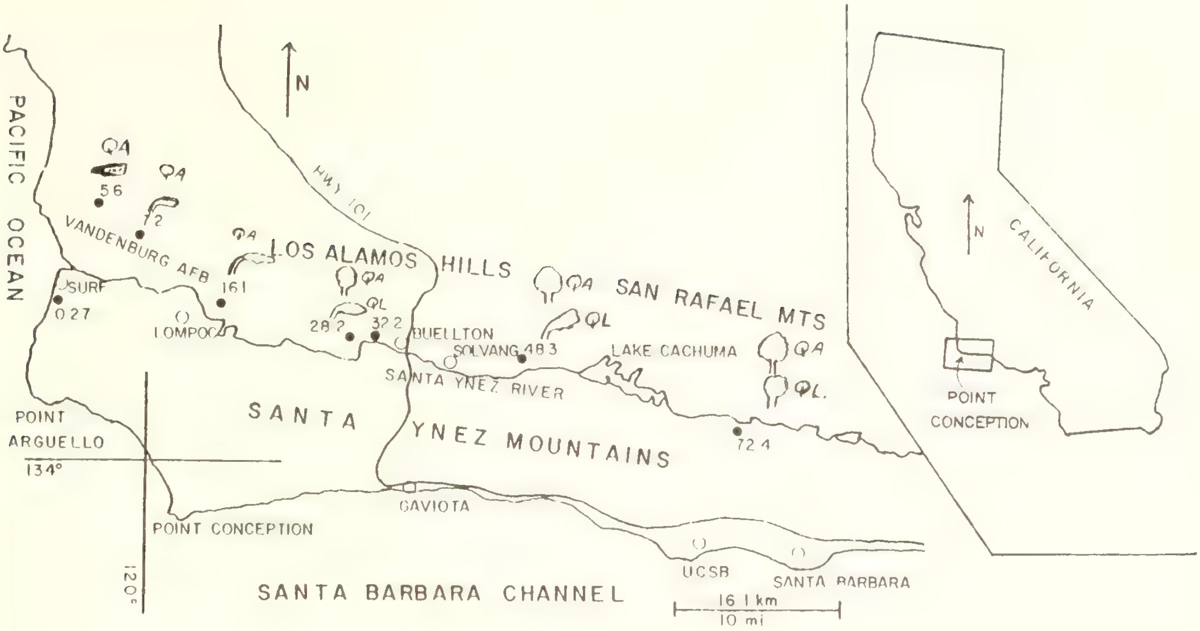

Figure 1--Map depicting location of the study area. Numbers beside each site represent distance inland from the w-facing coastline (Surf) in km. The valley is protected from a marine influence from the south by the Santa Ynez Mountains. Drawn figures depict the approximate growth forms of the two oak species.

facing) as opposed to the leeward (east facing) portions of the tree. Sea salt aerosol (Cl^-) could also produce a similar asymmetrical growth form. The trees, which act as wind filters, receive more sea salt deposition on windward than leeward leaves. The salt is foliarly absorbed with subsequent death of leaves and buds on the more exposed (windward) portions of the tree. The degree of lean is directly proportional to the long term intensity of salt spray damage.

Figure 2 diagrams the sequence of injuries that results in the formation of curved stems: (A) A twig which grew during a period of low spray intensity. The dark portion of the twig represents the dead tip which was killed when spray intensity increased to killing proportions; (B) Represents two twigs which grew during the next period of low spray intensity. During the next period of high intensity, the windward twig was killed since the leeward twig was protected by the seaward leaves and branches; (C) The same type of injury has occurred during another period of growth; (D) and (E) The older dead twigs have begun to decay

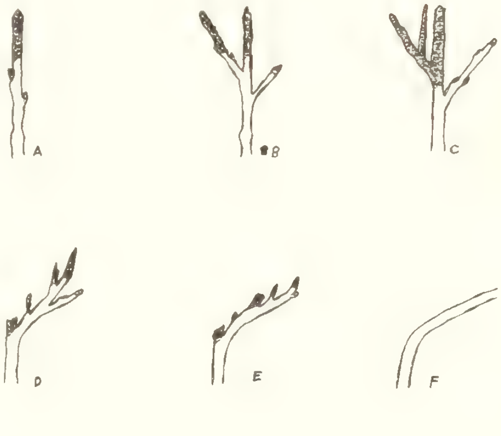

Figure 2--Diagram depicting the sequence of injuries that result in the formation of curved stems as a result of sea salt aerosol (Boyce 1954).

and expose some of the leeward twigs; (E) The living portion of the stem is composed of parts of several twigs which are oriented in the shape of an arc; (F) Represents the stem at some later time when radial growth has covered the dead twig scars (Boyce 1954).

METHODS

Wind (anemometers) and salt aerosol sampling equipment were placed in the field at selected sites (.27, 5.6, 7.6, 16.1, 28.2, 32.2, 48.3, 72.8 km) inland from the coast and monitored on a weekly basis for 3 years (1971-1974). Salt aerosol was collected on 6.45 cm^2 filter paper discs attached to microscope slides. The Cl$^-$ ion was determined by mercuric nitrate titration. For Cl$^-$ content in plant material the method of Brown and Jackson (1955) was used. Na$^+$ analysis was done by flame photometer.

AEROSOL ADVECTION

Salt aerosol was measured in significantly high quantities up to distances of 48.3 km inland. Average weekly aerosol values for the 5.6, 16.1, 28.2, 48.3 and 72.8 km sites were 1.65, 0.49, 0.45, 0.2, and 0.02 mg Cl$^-$/20 cm^2/week. Higher aerosol values were found during spring and early summer months than during late summer and fall (fig. 3). Normal sea breezes produce small amounts of Cl$^-$ influx. Post-frontal onshore northwesterlies produce the greatest aerosol amounts, which occur during early spring months. Greatest aerosol values were found to be on ridge crests. Leeward exposures throughout the valley receive little aerosol.

FIELD OBSERVATIONS OF AEROSOL DAMAGE ON NATIVE OAKS

Leaf necrosis (salt burn) was observed on both oak species in the field. The symptoms were identical to those described in the literature for Cl$^-$ damage (Boyce 1951, Wells and Shunk 1938, Boyce 1954, Karschow 1958, Strogonov 1964).

The patterns of foliage damage observed were as follows:

1. Necrosis appears first at leaf tips as a browning area and proceeds along leaf margins in an inverted V pattern from leaf apex to petiole before leaf abscission from the stem occurs.

2. Necrosis was found to distances up to 60 km inland on Q. lobata; and 28.2 km for Q. agrifolia.

3. Windward exposed leaves on both tree species showed necrosis symptoms. None were found on the leeward leaves.

4. After the trees leaf out in February, symptoms occurred earlier in the season at sites located closer to the coast.

5. On sites where both species occur, damage appeared first on Q. lobata.

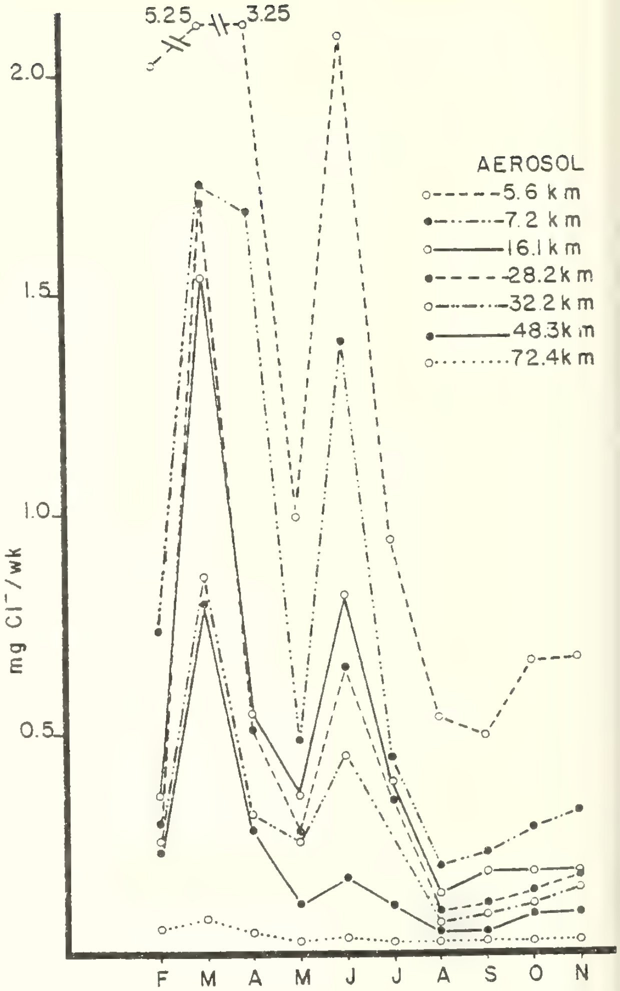

Figure 3--Salt aerosol values through time and space for 1973. Monthly values are derived from averages of weekly totals from all sources: impaction mg Cl$^-$/20 cm^2/wk + drip off + fog drip-sedimentation-precipitation.

6. New necrotic leaves appeared more frequently on trees closer to the coast. The quantity of leaves showing symptoms was greater at coastal than inland sites.

7. Leaf exposure time to salt-laden air before damage symptoms appeared is shorter for sites at more coastal locations.

8. More apical and terminal buds die on windward as opposed to leeward portions of the tree.

FOLIAR Cl^- ABSORPTION VALUES IN FIELD OAK SPECIES

To determine rates of Cl^- absorption in field oak species,one study tree at each of the 11 sites along the W-E transect was chosen. Equal exposure, vigor, size, maturity, and proximity to anemometers and aerosol sampling equipment were considered in tree selection.

Leaves were collected at 1-month intervals during the 1973 growing season. Three leaf types were chosen (when present) for the duration of the growing season (February-September) at each site: windward normal and necrotic leaves, plus leeward normal types. The windward side in all cases was facing the NW. For each leaf type, 3 samples were taken of 20-25 leaves per sample. Through the 5-7-month sampling period, leaves were chosen which had appeared on the trees since the initiation of sampling. In this way, the effect of leaf exposure time to the prevailing winds could be evaluated. Samples were transported to the lab in small closed plastic bags in an ice chest. In the lab, after fresh weight was recorded, each sample was placed in a 100-ml beaker with 50 ml of distilled water and swirled for 30 seconds to remove any external Cl^- from the leaf surface. Leaf samples were dried for 72 hours at 72-75°C after which dry weights were recorded. The samples were then crushed with mortar and pestle and placed in air tight containers. An analysis was then made of the Cl^- and Na^+ amount present in the leaf tissue. Cl^- is calculated as percent sap instead of percent dry weight, so that overestimations of Cl^- would be avoided and also allow comparison of different species and leaf ages (Cassidy 1966).

Internal Cl^- values for both oak species were found to be from 0.01 to 0.11 percent sap for leeward normal leaves; 0.01 to 0.46 percent sap for windward normal foliage; and for windward leaves on which salt burn symptoms could be observed, values ranged from 0.51 to 3.02 Cl^- percent sap. Leaf moisture values were also usually higher for windward leaves than leeward leaves. Cl^- levels were from 2X-8X higher in necrotic leaves than windward normal or leeward normal leaves.

Young foliage which has not been exposed to salt-laden winds is low in Cl^- (figs. 4 and 5). With increased exposure time the Cl^- levels for windward-normal foliage increase until sufficient Cl^- has been absorbed to produce observable salt burn symptoms. Note that at 32.2 km inland, it took 5 months of leaf exposure for *Quercus agrifolia* to produce a salt-burned leaf (fig. 4). One month less of leaf exposure was required to produce necrotic symptoms in *Quercus lobata* foliage at this same distance from the coast. Comparing both oak species at similar distances inland with equal topographic exposure, *Quercus lobata* had a higher rate of foliar Cl^- absorption in windward leaves than did *Quercus agrifolia*.

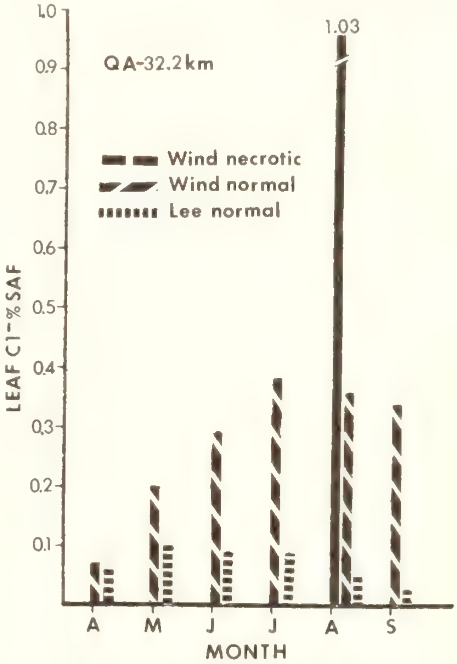

Figure 4--Foliar Cl^- values for *Quercus agrifolia* at a distance of 32.2 km inland from the salt aerosol source. Note that increased leaf exposure time to the salt-laden winds cause increasing amounts of chloride in wind normal leaves.

Figure 5 shows that it took 6 months of leaf exposure to the lower amounts of aerosol contained in the wind at 48.3 km inland before enough Cl^- could be absorbed to produce visual signs of salt burn damage. This is a 2-month longer exposure time than for *Quercus lobata* at the 32.2 km site. *Quercus agrifolia* at the

48.3 km site showed no necrosis symptoms, with windward normal leaf Cl^- amounts being only slightly greater than the low Cl^- levels in the leeward leaves.

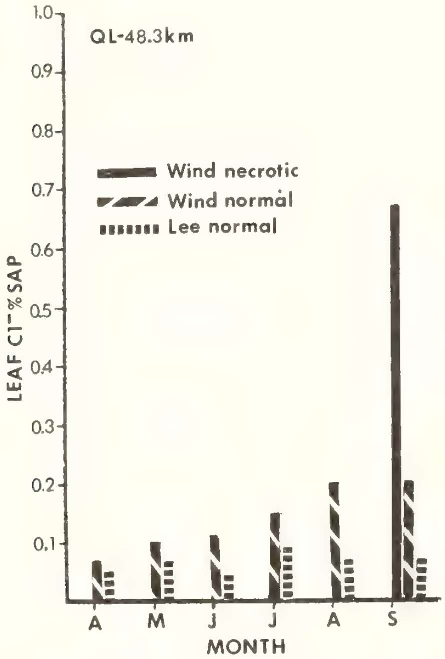

Figure 5--Foliar Cl^- values for Quercus lobata by month of leaf exposure time at a distance of 48.3 km inland from the salt aerosol source.

At the 72.4 km control site where both oak species show no asymmetrical growth, the foliar Cl^- levels for both oak species remain identical for windward and leeward leaves, never becoming greater than 0.04% Cl^- percent sap.

MECHANISM FOR DIFFERENTIAL Cl^- ABSORPTION RATES BETWEEN THE TWO OAK SPECIES

The fact that at 28.2 km inland Quercus agrifolia has a normal canopy and Quercus lobata still exhibits an asymmetrical form demonstrates that these two oaks have differing responses to similar aerosol levels. The leaf Cl^- concentration required for necrotic symptoms to be produced is the same for both oak species. The differing growth forms may therefore be explained in terms of varying rates of foliar Cl^- absorption.

The fact that Q. lobata has a faster rate of foliar Cl^- absorption and is thus more sensitive to salt laden winds is due to several leaf morphological traits.

1. When subjected to similar wind speeds, the leaves of Quercus lobata tend to flutter more in the airstream than do leaves of Quercus agrifolia. This is due to the fact that Quercus agrifolia has a shorter petiole and is a more xeric leaf type than Quercus lobata. This action can cause cracks in the leaf cuticle and therefore increase the rate of Cl^- uptake (Karschow 1958, Boyce 1954).

2. Observation indicates that Quercus agrifolia leaves are not as wettable as those of Quercus lobata. This is due to the smooth thick cuticular surface and lack of dense concentrations of stellate hairs on the upper and lower leaf surfaces of Quercus lobata. Salt solution beads up and runs off much more rapidly on Quercus agrifolia. This has been described by others (Boyce 1954).

3. Leaves of Quercus agrifolia are more xeromorphic in nature than those of Quercus lobata. The leaves are more rigid as a result of increased amounts of supportive tissue. They have a thicker epidermal layer. The fact that xeric leaf morphology gives increased tolerance to salt spray has been observed by others (Salisbury 1805, Wells and Shunk 1938, Wells 1939, Moss 1949, Edlin 1943 and 1957, Oosting 1945, Kurauchi 1956, Martin 1959).

4. The difference in abundance of hairs found on the leaf surface of the two species suggests a mechanism for the differences found in their relative tolerance to sea-salt aerosol. This hair covering which is much more abundant on Quercus lobata has a multipurpose function in regard to foliar absorption of salts. It provides more surface area for the impaction of aerosol particles, plus more surface area in contact with the salt solution for subsequent possible absorption through the hairs.

5. Another possible explanation is that foliar absorption does not occur throug the hairs themselves but via the plentiful supply of ectodesmata provided at the base of these tufted hairs (Franke 1967). These structures are found only in certain regions of the cuticle including rich supplies found in epiderma cells at the base of hairs (Martin and Juniper 1972, Franke 1967, Hull 1964).

Increased hair density would, therefore, imply increased numbers of ectodesmata. Quercus lobata with its greater hair density would thus potentially contain more sites for foliar absorption.

Besides the above morphological factors which could possibly cause Quercus lobata to have a greater foliar absorption rate, relative humidity also affects ion absorption rate. High relative humidities (above 75 percent) not only keep salt in solution on leaf surfaces but also permit the waxes of the cuticle to be in their most swollen state and thus more permeable for entry of external solutions (Woodcock 1949, Cadle 1966, Jacobs 1937, Winkler and Junge 1971, Martin 1959, Roffman 1973). As humidity decreases, salts crystallize out, with Cl^- remaining in solution the longest and hence providing a greater probability for leaf absorption (Harding, Miller and Fireman 1958).

Relative humidities were measured in the Santa Ynez Valley for a 6-month period and found to be above 75 percent at coastal sites (16.1 km) 82 percent of the time and at inland sites (28.2 km) for only 69 percent of the time.

In order to test the possibility that Quercus lobata has a greater foliar Cl^- absorption rate than Quercus agrifolia and also to see if relative humidity plays a role in rate of Cl^- uptake, a long-term differential relative humidity experiment was designed. Oak seedlings of both oak species were grown in the greenhouse until mature foliage was produced. Seedlings were from 10-20 cm in height. Plants were sprayed with one application of undiluted sea water until their leaves were just moist but not dripping. (Application comparable to field conditions.) One-half the plants for each species were placed in different sections of the greenhouse under varying humidity ranges. The high humidity greenhouse ranged between 60-93 percent, while the low humidity greenhouse was 38-60 percent. Thirty-six plants of each species were used. Three plants of each species were removed at specific intervals, washed, weighted, dried and analyzed for Cl^- content. Controls were sprayed with distilled water. Half the controls were analyzed immediately after spraying; the other half were left in their respective environments until the termination of the experiment. The results appear in figure 6.

A differential foliar absorption of Cl^- exists between Quercus lobata and Quercus agrifolia, the former species being less tolerant. Higher humidities produced greater rates of Cl^- uptake than lower humidities.

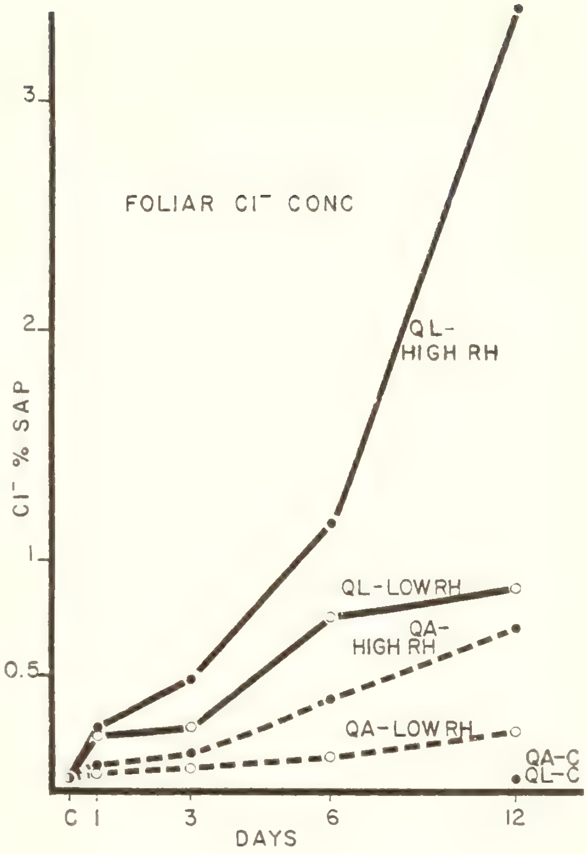

Figure 6--Leaf Cl^- concentrations of oak foliage following various lengths of exposure to foliar applied sea water spray at 2 different humidity ranges. QA= Quercus agrifolia; QL = Quercus lobata; RH = relative humidity; C = control.

Similar experiments over 24-hour periods demonstrated similar results. Others have found this same phenomenon in crop plants (Swain 1972).

CONCLUSION

The routine far inland advection of sea-salt aerosol along N-S oriented coastlines in California by the prevailing westerlies and postfrontal high pressure ridges causes abnormally high Cl^- aerosol values up to 48 km inland. The Cl^- ion is filtered out by the vegetation, NW-facing leaves receiving greater aerosol amounts than SE-facing leaves. High relative humidities in the valleys keep the aerosol in solution on leaf surfaces and maintain swollen leaf cuticles for maximum potential of Cl^- foliar absorption. Once absorbed, the Cl^- ion is transported to leaf margins and leaf necrosis symptoms become visible. Other Cl^- ions are transported to apical buds with resulting shoot tip death and leaf abscission. The same phenomenon continues, producing a pruned, asymmetrical growth form, the degree of lean proportional to the amount of salt spray absorbed. *Q. lobata* (Valley Oak) exhibits a greater degree of lean, away from the aerosol source, than *Q. agrifolia* (Coast Live Oak) at similar distances and exposures inland. This effect is due to the more mesic nature of the leaf and the presence of stellate hairs on the leaf surface. These morphological features cause Cl^- to be more rapidly absorbed by *Q. lobata* leaves and this is reflected in greater death of windward leaves and twigs which eventually produces a greater degree of lean than observed in *Q. agrifolia*.

Salt spray has been found to have an effect on tree growth symmetry of *Q. lobata* up to 50 km inland and on foliage leaves up to 60 km inland on a seasonal basis. Sea salt aerosol should not only be considered as a retarding factor when analyzing coastal strand situations but also when studying areas such as oak woodlands much further inland where vegetational responses can be observed.

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Quercus douglasii

Tolerance of Oaks to Flooding[1]

Richard W. Harris, Andrew T. Leiser, and Robert E. Fissell[2]

Abstract: Mature blue oaks (Quercus douglasii) and valley oaks (Q. lobata) growing on alluvial soils in central California withstood flooding for 50 to 98 days each of three years with little or no tree loss. Blue oak on shallower residual soils suffered 50 per cent mortality each year with similar flooding.

INTRODUCTION

Established native oaks have the reputation of being sensitive to changes in their soil environment, even changes considered improvements for many plants. Almost without exception, moisture and aeration changes account for most of the difficulties.

Oaks, therefore, were of particular interest when we began studies in 1967 on the flood tolerance of woody plants in the drawdown zones of several central California reservoirs. The gross-pool levels of two reservoirs (Black Butte, north of Orland,and Terminus, east of Visalia) were raised (at least 13 and 25 feet respectively, above their original designed levels. We also surveyed Andrus and Brannan Islands in the Sacramento-San Joaquin Delta two years after they were flooded in 1972.

Blue oak, Quercus douglasii, was the most numerous oak at the two reservoirs. Nine large valley oaks, Q. lobata, were at Black Butte and a few mature interior live oaks, Q. wislizeni, grew at Terminus. Valley oak and pin oak, Q. palustris, were on Andrus and Brannan islands.

Most of the flooded trees at Black Butte were growing on a well-drained (when not flooded) alluvial fan. Most of the trees at Terminus were on shallow, residual, hillside soil. Those in the Sacramento-San Joaquin delta were on a well-drained, fine-textured organic soil.

At the two reservoirs, the lower trees were flooded beginning in early to mid-May. Andrus and Brannan islands were flooded beginning June 21, 1972.

RESULTS

Black Butte Reservoir

Fifteen of 16 mature blue oak trees survived 50 to 98 days of flooding during three of the four years they were flooded to a maximum depth of 8 to 10 feet of water over the ground (Table 1, fig. 1). Sixty-nine per cent survived flooding 96 to 110 days two of the years.

All of the valley oaks survived inundation for periods ranging from 63 to 110 days in 1967, Table 1. The maximum depth of water was between 5 and 12 feet.

Shoot growth of blue oak averaged about 25% more during each of the first three years of flooding than they did each of the two years before being flooded. Shoot growth was complete each year in early May before the trees were flooded. Trees on higher ground not subject to flooding but within 10 feet (elevation) of the 1967 high-water mark made at least 50 per cent more growth after flooding began than they did previously. Vertical areas of bark were killed on trunks of many blue oaks subjected to flooding. Callus growth was vigorous, cracking the dead bark on surviving trees (fig. 2).

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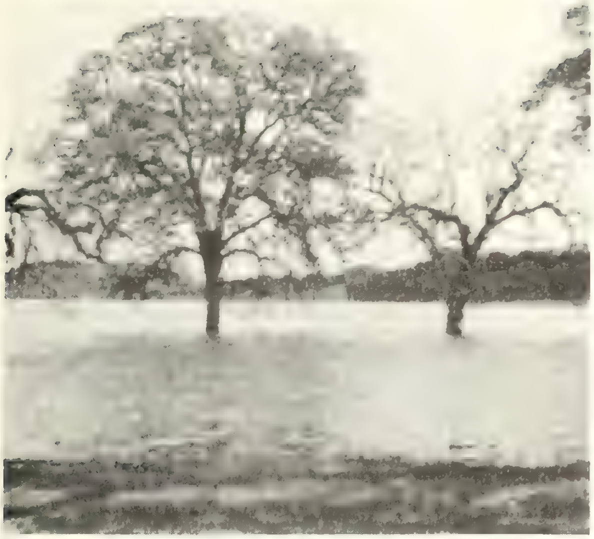

Fig. 1. Valley oak (Quercus lobata), left, and blue oak (Q. douglasii) on alluvial soil at Black Butte Reservoir in April 1969. The two trees were flooded at least ninety days in 1965 and 1967 and forty days in 1966 and 1969. Valley oaks leaf out earlier than blue oak.

Terminus Reservoir

Flooding for 68-86 days (20-30 ft. depth) in 1967 and 72-76 days (10-15 ft. depth) in 1969 killed half of the blue oak trees each year, Table 2. The maximum depth of water was 20 to 25 feet in 1967 but only 5 to 10 feet in 1969.

Shoot growth of surviving blue oaks was greater on flooded trees compared to that of the same trees on higher ground not flooded. Number of shoots were not noticeably affected unless the branch was submerged. Branches died if completely submerged longer than two weeks. Bark was killed on flooded trees similar to those at Black Butte.

The few interior live oaks all died if water covered the soil around their trunks for longer than one week.

Andrus-Brannan Islands

Both pin oaks survived flooding to a depth of 10 feet for 92 days. All nine of the valley oak trees survived 61 days of flooding to a depth of 4 feet.

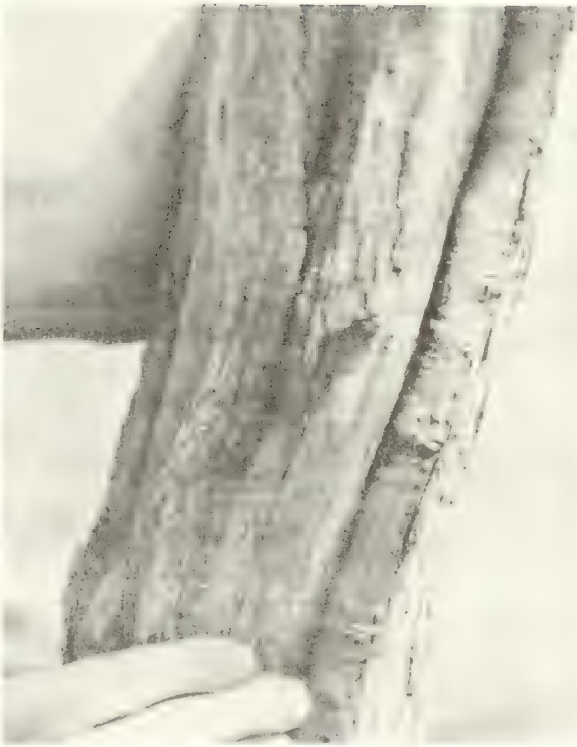

Fig. 2. The bark on a number of flooded blue oak died in vertical strips. Note ridges of bark between two dead areas. Callus growth is vigorous. Black Butte, 1969.

Other United States Studies

Five species of oak tolerant to flooding were reported in two to six studies reviewed in a survey of such studies in the United States (Whitlow and Harris, 1978), Table 3. Seven species were found to be intolerant to flooding in 1 to 4 reports. Reports on six other species were either inconclusive, contradictive, or indicated the species were only slightly tolerant.

Several oak species appear to be tolerant to prolonged periods of flooding; others quite sensitive. Even though the soils were saturated for these long periods, the water was not stagnate so that aeration apparently was sufficient.

RECOMMENDATIONS

Recommendations made in 1969 have been supported by observations since. These were for recreation site specifications based on an expected 50% survival of trees flooded at maximum gross pool levels for newly constructed reservoirs.

1. Remove all interior live oak, Quercus wislizenii, below expected maximum gross pool.

2. Leave blue oak, Q. douglasii, which will not be flooded to more than 75% of their height at the mean gross pool in the drawdown areas on previously dry (xeric) hillsides which may be flooded for 80 days or less and on more moist (mesic) alluvial fans which may be flooded for 100 days or less.

3. Valley oak, Q. lobata, should take equal or greater flooding than blue oak. Its maximum tolerance was not reached by 100 days of flooding of trees on an alluvial fan.

4. Limbs at elevations where 2 weeks or more of flooding is likely could be removed at time of site development or after death by flooding.

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1978. Flood tolerance in plants: a state-of-the-art review. Environmental and Water Quality Operational Studies. U.S. Army Engineers Technical Report E-79-1.

Table 1. Survival of blue and valley oaks following inundation of Black Butte Reservoir, California, 1965-70

Maximum water depth (1967) ft.	Days water covered soil under trees				Blue oak			Valley oak	
	1965	1966	1967	1969	Live trees 1965	Survival[2/] 1967	Survival[2/] 1969	Live trees 1965	Survival[2/] 1969
					no.	no.	no.	no.	no.
0-2[1/]	0	0	0-15	0	11	11	11	-	-
2-4	0-1	0	16-62	0-6	24	24	24	-	-
4-6	2-56	0	63-71	7-39	18	18	18	1	1
6-8	57-90	0	72-87	40-54	11	11	11	4	4
8-10	91-95	0-51	88-98	55-64	16	15	15	2	2
10-12	96-100	52-65	99-110	65-74	13	9	9	2	2
12-13	101-103	66-72	111-123	75-80	5	2	2	-	-

[1/] Trees were grouped into different elevation groups based on the 1967 flooding. Length of flooding and tree numbers within an elevation group row are for the same trees.

[2/] Survival was determined the spring after the year of flooding indicated.

Table 2. Survival of blue oaks following inundation at Terminus Reservoir, 1967-70

Maximum water depth (1967) ft.	1965	1967	1969	Live trees 1966	Survival, spring after flooding 1967		1969	
				no.	no.	%[2/]	no.	%[3/]
0-5[1/]	0	0-34	0	6	6	100	6	100
5-10	0	35-47	44-47	8	7	90	5	71
10-15	0-17	48-56	72-76	11	10	91	5	50
15-20	18-28	57-67	80-87	7	6	86	2	33
20-30	29-14	68-86	93-114	12	6	50	1	16

[1/] (#1 above)

[2/] Per cent of trees alive in 1966.

[3/] Per cent of trees alive in 1967.

Table 3. Observations in the United States as to flooding tolerance of oak species in native stands, or laboratory and field tests (Whitlow and Harris, 1978).

Species	Common name	Number of reports			
		Tolerant	Slight Tolerance	Intolerant	Uncertain
Q. lyrata	Overcup	6			
Q. nigra	Water	3			
Q. nuttallii	Nuttall's	2			
Q. palustris	Pin	4			
Q. macracarpa	Bur	3		1	
Q. rubra	Red	1		4	
Q. alba	White		1	1	
Q. biocolor	Swamp White		1		
Q. falcata	Spanish		1	3	
Q. marlandica	Black jack			2	
Q. montane	Chestnut			1	
Q. muehlenbergii	Chinquapin			3	
Q. prinoides	Dwarf Chinquapin			1	
Q. stellata	Post			4	
Q. velutina	Black			3	
Q. shumardii	Shumard				2

Animal Damage to Valley Oak Acorns and Seedlings, Carmel Valley, California[1]

James R. Griffin [2]

Abstract: I sampled acorn production by mature valley oaks and studied predation on the acorn crop and resulting seedlings. Birds harvested much of the crop from the tree crowns. Insects ruined 20 pct of the mature acorns that hit the ground. Still some 200 viable acorns/m^2 may fall under productive trees in good years. In absence of cattle and deer these acorns remain on the ground until rodents harvest most of them in the winter. Inside a deer exclosure accessible to rodents about one seedling/m^2 germinated and grew, but these seedlings rarely survived rodent predation for more than 4 years. Pocket gophers were the most important predator in this area. When rodents were excluded, as many as 24 seedlings/m^2 grew; over half survived for 3 years.

INTRODUCTION

Public concern about the shortage of young valley oaks (Quercus lobata Née) is growing. In large portions of California's oak woodland few saplings are present to replace the veteran valley oaks dying of natural causes or being destroyed by urban and agricultural development (Griffin 1977, Steinhart 1978). Although the problem of low natural regeneration has been publicized, only limited research has been devoted to its causes.

Oak woodlands around Carmel Valley typify the regeneration problem. Since 1967 I have studied valley oak reproduction on a variety of small plots at the Hastings Natural History Reservation. In this paper I discuss acorn and seedling conditions on these plots over a longer time span than previously reported (Griffin 1971, 1976) and add new data obtained from rodent exclosures.

DAMAGE TO ACORNS

Bird Predation

Birds remove much of the maturing acorn crop from valley oak crowns. In poor years they may harvest all the crop before it falls. Acorns picked by acorn woodpeckers (Melanerpes formicivorus) are lost to oak regeneration; woodpeckers drop few acorns while eating them fresh or when storing them where they cannot germinate. Throughout the oak woodland scrub jays (Aphelocoma coerulescens) are important acorn consumers. Other Corvidae are locally important. At Hastings scrub jays have removed acorns from individual valley oaks at rates exceeding 400/hour. These acorns however, are not all lost to regeneration. Scrub jays store acorns in the ground and litter, and the numerous acorns which are not found and eaten later are effectively "planted."

Insect Losses

Several types of insects damage valley oak acorns (Brown and Eads 1965). Filbertworms (Melissopus latiferreanus) and filbert weevils (Curculio occidentis) infest many mature acorns; however, such larvae in the acorns do not always prevent germination. The only data I have on the extent of crop loss to insects is from one set of long-term acorn traps (four 0.25 m^2 traps under each of four trees). Over an 8-year period about 21 pct of the fully developed acorns that dropped into the traps were clearly non-viable due to insect damage.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, Calif., June 26-28, 1979.

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Seasonal losses, mainly due to filbert weevils, ranged from 0 to 31 pct.

Mammal Damage

Despite insect and bird losses, acorns accumulate beneath valley oaks during October and November of good seasons. Trap data show that more than 200 viable acorns/m^2 may fall from productive trees. The four trees in the acorn trap survey averaged 34 viable acorns/m^2 (range 7-74 acorns/m^2) over a 9-year period. But these acorns do not remain on the ground long if unprotected. In pastures cattle eat many, and over the entire oak woodland black-tailed deer (Odocileus hemionus) aggressively forage for acorns. At Hastings only rarely are valley oak acorns lying on the ground by January, even after bumper acorn crops.

My predation studies give some data on the loss of acorns on the ground in the absence of cattle and deer. All studies were run under the same valley oak within a large deer exclosure (Griffin 1976). In the first study 233 naturally occurring acorns on four 25 X 25 cm quadrats were watched starting in Novmeber 1970. Few acorns disappeared until pocket gophers (Thomomys bottae) became active near the quadrats in February 1971. By March only 103 (44 pct) of the acorns remained.

In the second study 200 acorns from under the tree were arranged into five groups of 40; half of each group was covered by a screen cage to exclude birds. Most of the unscreened acorns were damaged soon after placement in November 1971. Although the punctures on these acorns looked like scrub jay pecks, no jays were ever seen "pecking." This type of damage did not occur again. Pocket gophers were also active at the start of this study. By March 1972 no acorns remained on the quadrats.

In the last two studies 250 acorns were arranged into 25 groups of 10 with half of each group covered to exclude birds. The numbers of acorns on the quadrats were:

Date	Open quadrats	Covered quadrats
Nov. 1975	125	125
Jan. 1976	1	30
March 1976	1	18
Nov. 1976	125	125
Jan. 1977	31	65
March 1977	16	36

In these last two studies acorns disappeared sooner from the open than from the screened quadrats, but there was no evidence that birds were involved. Birds did not take acorns from nearby open rodent exclosures at this time. Possibly deer mice (Peromyscus spp.) foraged over the unscreened areas sooner than the screened areas, although they had no trouble getting under the screens. In the third study deer mice left partially eaten acorns in 10 of 25 screened quadrats. There were active gopher holes in eight of the 25 screened quadrats in the third study and active holes in 20 out of 25 quadrats in the last study.

Of the 933 acorns monitored in these studies 756 (81 pct) were eaten on the spot or carried away. Most of the remaining acorns germinated. Seventy of the germinating acorns effectively rooted and produced seedlings, but none of the seedlings survived continuing rodent predation.

DAMAGE TO SEEDLINGS

Planted Seedlings

In 1967 during a dry winter, 16 germinating acorns were planted in a grass plot (Griffin 1976). The seedlings in this south slope savanna died by early summer. The following autumn I planted 160 acorns in the same grass plot. Despite starting in a wet winter, seedling survival was poor, and by the eleventh season no seedlings remained. In the winter of 1967 I also planted 16 acorns in an adjacent cleared plot. These seedlings without grass competition grew large enough to attract pests. Browsing by brush rabbits (Sylvilagus bachmani) and stem girdling by flatheaded borers (Chrysobathris mali) contributed to the death of all seedlings in this plot by the eighth season.

On a north-facing woodland site I planted 16 acorns in 1967 in a cleared exclosure (Griffin 1976). In this cool, shady plot all the seedlings grew well for two seasons, but later stem damage by borers and browsing by rabbits caused some mortality and slowed height growth. In the eleventh season survival was 38 pct; heights averaged 19 cm (range 7-39 cm).

In 1973 I planted 960 acorns using three treatments in five habitats. Two treatments were within rodent exclosures at each habitat. However, rodents penetrated the exclosures and compromised the results. The unprotected treatments in which deer and small mammals had free access are worth mentioning. Sixty-four acorns were planted in each of five unprotected plots. At the end of the fifth season no seedlings remained in four plots. In the fifth plot, on the north-facing woodland mentioned above, five heavily browsed seedlings survived. Thus, less than 2 pct of 320 unprotected seedlings remain; the tallest is 7 cm high.

Natural Seedlings

My study of natural valley oak seedling survival involved a healthy mature tree in a savanna habitat (Griffin 1976). This area was part of an old hayfield which had been uncultivated and ungrazed for 40 years. Despite this lack of "ranching" disturbance, the oaks in this habitat have produced no saplings during those 40 years. The study tree is now within a 0.2 ha deer exclosure and has an 11 m^2 rodent exclosure under the outer edge of its canopy. This oak is consistently the most productive tree monitored in the acorn trap survey. Even though the crop failed in two out of nine seasons,it averaged 74 viable acorns/m^2 (range 0-207 viable acorns/m^2).

In 1971 I started marking each seedling with plastic flagging and aluminum tag on a small stake offset from the stem. The 1970 acorn crop was so abundant that I could not keep up with all the new seedlings, but over 300 were marked. Virtually all seedlings appearing each season since have been inventoried (Table 1). Seedlings were checked several times each season, and those with live root-crowns in the fall, regardless of shoot condition, were counted as survivors. Since 1971 I marked a total of 825 seedlings in the large area accessible to rodents under the tree. At least 330 seedlings started in the small rodent exclosure during the same period (the exclosure was not fully rodent-proof until 1974).

Too many seedlings were involved to keep frequent records on the condition of every seedling year after year. The most detailed data on the fate of seedlings was from the 1975 acorn crop (Table 2). Few of these seedlings died because of competitive or allelopathic effects of the grass cover; they died because predators ate them. Outside the exclosure only four of 120 seedlings germinating in 1976 were found dead in "intact" condition. Gopher digging was associated with all other missing seedlings. Some seedlings in poor health may have been eaten by gophers before they could die, and gophers may have dug up and destroyed some dead seedlings before I could count them as dead. But the circumstantial evidence suggests that gophers are by far the major source of seedling mortality here.

Within the exclosure 106 out of 251 seedlings germinating in 1976 died during the following three seasons. Many of the dead seedlings had been browsed by grasshoppers. Since the first two seasons were the driest on record at Hastings, the 58 pct survival in dense grass cover is impressive. As of 1978 this tiny exclosure had 192 live seedlings. Even with heavy insect mortality in the future, the plot is vastly overstocked. Just one of the large healthy seedlings that started in 1974 should be able to replace the parent tree.

CONCLUSIONS

Under Carmel Valley conditions viable acorns fall from many trees in many seasons in spite of heavy losses to birds and insects. When cattle and deer are excluded, the acorn supply often exceeds the capacity of rodent

Table 1-- Valley oak seedling survival inside and outside a rodent exclosure surrounded by a deer exclosure; maximum number starting in a given season and surviving in successive seasons

Date	Start	RODENTS Survivors, end of season					Start	NO RODENTS Survivors, end of season				
		1	2	3	4	5		1	2	3	4	5
							No./m^2					
1971	1.3	0.7	0.4	0.3	<0.1	0						
1972	0.2	0.1	0.1	<0.1	0							
1973	0.1	0.1	<0.1	0								
1974	<0.1	<0.1					0.6	0.6	0.6	0.6	0.6	0.6
1975	?	0					0	0				
1976	0.5	0.3	0.1	0.1			23.7	19.0	16.4	13.7		
1977	0.6	0.4	0.1				3.0	0.8	0.5			
1978	0.7	0.5					4.1	3.4				

Table 2-- Condition of valley oak seedlings from the 1975 acorn crop inside and outside a rodent exclosure surrounded by a deer exclosure during three growing seasons

Seedling condition	RODENTS			NO RODENTS		
	1976	1977	1978	1976	1977	1978
DEAD OR MISSING	No./m^2					
Positive gopher damage, seedling within fresh gopher hole	<0.1	<0.1	<0.1			
Probable gopher damage, fresh gopher hole near marker, seedling missing	0	0.1	<0.1			
Possible gopher damage, seedlings and marker lost in gopher digging	0.2	0.1	0.1			
No rodent damage, seedling intact	0	<0.1	<0.1	4.7	2.6	2.6
ALIVE						
Stem dead, root alive	0.1	<0.1	0	2.1	3.3	0.6
Leaves dead or browsed, stem alive	<0.1	0.1	<0.1	2.1	6.4	0.7
Stem with live leaves	0.2	<0.1	0	15.4	6.7	12.4

predators. The remaining acorns germinate, and seedlings grow. On exposed south aspects seedling survival is nil; on north aspects or in partial shade seedlings are able to survive in grass cover even in dry years, up to 1/m^2. But the seedling supply seldom exceeds the capacity of rodent predators. Rarely do unprotected seedlings survive for more than a few years. Although several rodents and other small mammals browse seedlings, pocket gophers cause the greatest damage. When rodents are excluded, seedling survival is much higher. In favorable habitats seedling density in rodent exclosures soon exceeds 10/m^2. Even though these seedlings will experience insect losses, an excess of saplings will result.

Local seedling damage by small mammals, particularly by pocket gophers, can prevent the development of valley oak saplings. When seedlings did achieve sapling size in the past, either the supply of acorns and seedlings must have been great, the small mammal damage to seedlings must have been less, or some combination of the two. I doubt that the acorn supply was greater then unless insect losses were lower. My opinion is that small mammal damage is now at a very high level.

Why small mammal levels are now so high must remain speculative, but the introduction of highly nutritious herbs (seeds of Avena spp., roots of Erodium spp., etc.) into the oak woodland may have improved the habitat for many rodents. Whether the current seedling predation problem is a permanent threat to valley oaks is not clear. These trees which grow for centuries can wait a long time for the right combination of regeneration conditions.

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Products

Quercus douglasii

Birds of California Oak Habitats—Management Implications[1]

Jared Verner[2]

Abstract: About 110 species of birds can be observed during the breeding season in California habitats where oaks form a significant part of the tree or shrub canopy. Many of these birds use the oaks for foraging, nesting, or perching, and many regularly eat acorns. A guild approach to management, with selection of appropriate indicator species, is recommended. Management of oak habitats for birds should emphasize maintenance of mixed-species, uneven-aged stands where sites permit, and should provide for a continuing, abundant supply of acorns. Large, old trees are particularly important to birds, because they provide a wider array of foraging sites, tend to produce more acorns, and are best suited to excavation of cavity nests. Where present, a shrub layer should be maintained. Management plans for oak stands must consider adjacent, non-oak sites, because many bird species found there regularly exploit oaks.

INTRODUCTION

An estimated 15 to 20 percent of California's land base supports plant communities in which oaks (Quercus spp.) comprise a significant portion of the tree or shrub canopies, or both.[3] About 110 bird species occupy California oak habitats during the breeding season, so that the management of oak stands in a manner that will not unduly depress any bird species' numbers is truly a formidable task.

The several species of oaks represent a wide variety of sizes and shapes, from shrubs to large trees. Some species are deciduous, others are evergreen. Some have dense crowns, allowing little light to penetrate to the ground, although light easily filters through the canopies of other species. The various species differ in bark texture, leaf sizes and shapes, and in many features of their flowers and fruits. Students of avian ecology know that differences of these kinds are vital to habitat selection by different species of birds, particularly with reference to their foraging ecologies. Each bird species differs in one or more ways from all others in the kinds of places it seeks its food, or in the manner it obtains the food, or both. In spite of the variety within and between oak habitats, however, Small (1974, p. 205) writes that "the differences in the quality of bird life are not as great." In a general sense, Small's statement is true, but differences do exist in the bird species composition of different types of oak woodlands, and birds use different oak species in different ways. Perhaps more than anything else, Small's statement serves to underscore our general lack of knowledge about the important relationships between birds and oaks in California.

In preparing this report, I was repeatedly disappointed by the lack of adequate information. It seems that the most valuabl contribution to be made here is to catalog the areas in which our limited knowledge prevents sound management of California oaks for the maintenance of bird populations.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Research Wildlife Biologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Fresno, California.

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This paper is confined to those species of birds that use California oak habitats during the breeding season. I believe proper management of oaks for breeding birds only should provide adequately for those species that use oaks at other times of the year. Densities of birds in oak habitats are considered--the data show this to be one of the weakest points in the knowledge needed by managers. Information is provided on the ways in which birds use oaks, and management of oak habitats for maximum benefit to birds is discussed. My approach is necessarily qualitative, as the required quantitative information simply is not available for the vast majority of questions of interest to land managers.

BIRDS OF CALIFORNIA OAK HABITATS

Assembling a list of bird species that use oak habitats in California is complicated by the realities of vegetation. Oak habitats commonly are adjacent to other quite different habitats with different complements of birds that make use of the oaks. Oaks often share the canopy with other species of trees that attract bird species that might otherwise be absent. The nature of the understory vegetation--percent cover by shrubs and herbs--profoundly affects the composition of the avian community. Seasonal availability of water is also important.

The list of bird species (table 1) was compiled from a number of sources. Miller's (1951) assignment of California birds to various habitat types was the primary reference. Included are all species he specified as using oak woodlands and savannahs. A few additional species were added from Small (1974), and from annual breeding bird censuses taken in cooperation with the National Audubon Society. Because they are not usually regarded as birds of oak habitats, several species on the list require explanation.

Many birds occur regularly in oak stands because their preferred habitat type regularly occurs together with oaks (table 1). For example, Miller did not indicate that California thrashers or wrentits exhibit any selectivity for savannah or oak woodland types. Both species show first preference for chaparral. Miller, however, did include Bewick's wren and rufous-sided towhee in his oak woodland list; these species also show first preference for chaparral. In my opinion, because chaparral so frequently intermixes with oak stands, all of these species should be considered in plans for oak management. Censuses of breeding birds in oak habitats (table 1), for example, reported breeding by nine of 14 species assigned first preference for chaparral by Miller (1951). Censuses did not include the ranges of two other chaparral birds--California condor and mountain quail--and the California thrasher probably had finished nesting by the time censuses were begun.

Twenty-four species, including the green heron, wood duck, and black phoebe, were classed by Miller to have primary affiliation with riparian sites. Breeding was confirmed for 13, and only three were not observed on any census. Use of oak stands by most of these species depends on an associated riparian habitat.

Species that show primary preference for conifer forests--Miller's coastal, montane, and subalpine types--sometimes include available oak stands within their territories. We find some species on the list, therefore, that may be a surprise to some ornithologists; for example, the pileated and white-headed woodpeckers, olive-sided flycatcher, mountain chickadee, pygmy nuthatch, brown creeper, winter wren, golden-crowned kinglet, and pine siskin. Some of these species were observed--even confirmed as breeders--on a number of the censuses of breeding birds in oak habitats, particularly in habitats along the coast (table 1).

If we consider the variety of growth forms taken by oaks, the widespread distribution of oak habitats in California, and the frequent association of oak habitats with other types, it is not possible to put together an unambiguous list of bird species dependent upon oak habitats in California. Given the list in table 1, an ornithologist experienced with California birds might wish to begin dropping out those species whose association with oak types is clearly peripheral. These might include, for example, the green heron, ring-necked pheasant, black phoebe, cliff and rough-winged swallows, cactus wren, golden-crowned kinglet, yellow-rumped warbler, yellow-breasted chat, and white-crowned sparrow. Another ornithologist might have different choices. Perhaps some would even expand the list to include such species as the great blue heron (*Ardea herodias*) and great egret (*Casmerodius albus*) because they sometimes establish rookeries in valley oaks (*Quercus lobata*)[4,5] and live oaks (*Quercus agrifolia*).[6]

Another approach would be to compile a list based on the frequency of occurrence of species in the various sites sampled for breeding birds (table 1). Rufous-sided towhees, for example, Table 1--Breeding bird species associated with California habitats in which oaks (*Quercus* spp) comprise a substantial part of the canopy.

Species	Habitat selection[1/]		Breeding censuses[2/]					Oaks used for...		References[3/]
	Rank	Preferred type	A	B	C	D	E	Food	Nesting	
Green Heron (*Butorides virescens*)		Lacustrine waters				33	6		Open nest	Dawson 1923
Wood Duck (*Aix sponsa*)		Lacustrine waters				33	6	Acorns[f] [4/]	Secondary cavities	Bent 1923, Dawson 1923, Van Dersal 1940, Barrett and others[5/]
Turkey Vulture (*Cathartes aura*)	1	Savannah	25			33	12			
California Condor (*Gymnogyps californianus*)	3	Cliffs, chaparral								
White-tailed Kite (*Elanus leucurus*)	3	Riparian woodland				33	6		Open nest	Dawson 1923, Bent 1937, Waian 1973
Sharp-shinned Hawk (*Accipiter striatus*)	3	Montane forest								
Cooper's Hawk (*Accipiter cooperii*)	2	Riparian woodland		20		33	12		Open nest	Dawson 1923, Grinnell and Miller 1944, Fitch and others 1946
Red-tailed Hawk (*Buteo jamaicensis*)	1	Savannah			20	33	12		Open nest	Ritter[6/]
Red-shouldered Hawk (*Buteo lineatus*)		Riparian woodland							Open nest	Dawson 1923, Ritter[6/]
Swainson's Hawk (*Buteo swainsoni*)	1	Savannah							Open nest (uncommon)	Bent 1937
Golden Eagle (*Aquila chrysaetos*)	1	Savannah							Open nest	Dawson 1923, Bent 1937
American Kestrel (*Falco sparverius*)	1	Savannah			60	33	24		Secondary cavity	Verner[7/], Ritter[6/]
California Quail (*Lophortyx californicus*)		Chaparral	50	100	60	67	71	Acorns[d]		Van Dersal 1940, Martin and others 1951, Leopold 1977
Mountain Quail (*Oreortyx pictus*)	2	Chaparral						Acorns[d]		Bent 1932, Martin and others 1951
Ring-necked Pheasant (*Phasianus colchicus*)		Grassland				33	6	Acorns[c]		Bent 1932, Van Dersal 1940, Barrett and others[5/]
Turkey (*Meleagris gallopavo*)		Oak woodland						Acorns[f]		Bent 1932, Van Dersal 1940, Martin and others 1951
Band-tailed Pigeon (*Columba fasciata*)	1	Oak woodland	50	20			18	Acorns[f], new leaf buds	Open nest	Dawson 1923, Bent 1932, Van Dersal 1940, Grinnell and Miller 1944, Neff 1947, Martin and others 1951, Fry and Vaughn 1977
Mourning Dove (*Zenaida macroura*)	1	Savannah	50	80	80	100	76	Acorns[d]	Open nest	Van Dersal 1940
Roadrunner (*Geococcyx californianus*)		Desert scrub			40	33	18		Open nest	Dawson 1923, Grinnell and Miller 1944
Barn Owl (*Tyto alba*)	3	Cliffs, grassland			20		6		Secondary cavities	Bent 1938
Screech Owl (*Otus asio*)	1	Oak woodland	25	20		33	18		Secondary cavities	Dawson 1923, Grinnell and Miller 1944
Great Horned Owl (*Bubo virginianus*)	1	Oak woodland	25	40		33	24		Open nest	Bent 1938
Pygmy Owl (*Glaucidium gnoma*)	3	Coastal forest		20		33	12		Secondary cavities	Bent 1938
Spotted Owl (*Strix occidentalis*)	3	Coastal forest							Open nest, secondary cavities	Bent 1938
Long-eared Owl (*Asio otus*)	[illegible]	Riparian woodland								
Saw-whet Owl (*Aegolius acadicus*)	3	Montane forest								
Black-chinned Hummingbird (*Archilochus alexandri*)	2	Riparian woodland			80		24		Open nest	Dawson 1923, Bent 1940, Grinnell and Miller 1944
Anna's Hummingbird (*Calypte anna*)	2	Chaparral	50	100	80	100	82	Foliage insects, sap	Open nest	Dawson 1923, Bent 1940, Ervin[8/]

Table 1--Breeding bird species associated with California habitats in which oaks (Quercus spp) comprise a substantial part of the canopy. (continued).

Species	Habitat selection[1/]		Breeding censuses[2/]					Oaks used for...		References[3/]
	Rank	Preferred type	A	B	C	D	E	Food	Nesting	
Allen's Hummingbird (Selasphorus sasin)		Chaparral	50	80	20		41		Open nest	Bent 1940
Common Flicker (Colaptes auratus)	3	Riparian woodland	25	60	60	67	53	Acorns[d], insects from bark & wood	Primary cavities	Dawson 1923, Bent 1939, Van Dersal 1940, Grinnell and Miller 1944, Martin and others 1951
Pileated Woodpecker (Dryocopus pileatus)		Subalpine forest		20			6	Acorns[a], insects from bark & wood		Van Dersal 1940, Barrett and others[5/]
Acorn Woodpecker (Melanerpes formicivorus)	1	Oak woodland	50	40	80	100	65	Acorns[g], sap, bark insects, perch for hawking	Primary cavities	Beal 1911, Dawson 1923, Neff 1928, Bent, 1939, Grinnell and Miller 1944, Martin and others 1951, Bock 1970, MacRoberts and MacRoberts 1976
Lewis' Woodpecker (Melanerpes lewis)	1	Oak woodland						Acorns[e], perch for hawking	Primary & secondary cavities	Bent 1939, Van Dersal 1940, Martin and others 1951, Bock 1970
Hairy Woodpecker (Dendrocopos villosus)		Montane forest	50	60			29	Acorns[a], insects from bark & wood		Bent 1939, Van Dersal 1940, Barrett and others[5/]
Downy Woodpecker (Dendrocopos pubescens)	2	Riparian woodland	50	20	40	67	[illegible]	Acorns[b], insects from bark & wood	Primary cavities	Bent 1939, Van Dersal 1940, Martin and others 1951
Nuttall's Woodpecker (Dendrocopos nuttallii)	1	Oak woodland		40	100	100	59	Acorns[a], sap, insects from bark & wood	Primary cavities	Dawson 1923, Bent 1939, Miller and Bock 1972, Barrett and others[5/]
White-headed Woodpecker (Dendrocopos albolarvatus)		Montane forest							Primary cavities	Bent 1939, Verner[7/]
Eastern Kingbird (Tyrannus tyrannus)	1	Savannah								
Western Kingbird (Tyrannus verticalis)	1	Savannah			20	33	12	Perch for hawking	Open nest	Dawson 1923, Bent 1942
Cassin's Kingbird (Tyrannus vociferans)	1	Savannah						Perch for hawking	Open nest	Dawson 1923, Bent 1942
Ash-throated Flycatcher (Myiarchus cinerascens)	3	Pinyon-juniper woodland		80	80	100	65	Foliage insects, perch for hawking	Secondary cavities, natural cavities	Bent 1942, Grinnell and Miller 1944
Black Phoebe (Sayornis nigricans)		Cliffs, riparian woodland		20	20	67	24			
Western Flycatcher (Empidonax difficilis)	4	Coastal forest	100	80	20		53	Perch for hawking	Knot holes	Dawson 1923, Bent 1942, Root 1967
Western Wood Peewee (Contopus sordidulus)	3	Montane forest		60	60		35	Perch for hawking	Open nest	Dawson 1923, Bent 1942
Olive-sided Flycatcher (Nuttallornis borealis)		Montane forest	75				18		Open nest	Bent 1942
Violet-green Swallow (Tachycineta thalassina)	4	Montane forest	75	20		33	29		Secondary cavities	Newman and Duncan 1973, Verner[7/]
Tree Swallow (Iridoprocne bicolor)		Riparian woodland	25				6			
Rough-winged Swallow (Stelgidopteryx ruficollis)		Cliffs, grassland	25			33	12			
Cliff Swallow (Petrochelidon pyrrhonota)		Cliffs, grassland	25				6			
Purple Martin (Progne subis)	2	Coastal forest							Secondary cavities	Grinnell and Miller 1944
Steller's Jay (Cyanocitta stelleri)	4	Montane forest	100	100			53	Acorns[f], foliage insects	Open nest	Beal 1910, Van Dersal 1940, Bent 1946, Martin and others 1951
Scrub Jay (Aphelocoma caerulescens)	1	Oak woodland	50	80	80	100	76	Acorns[f], bark & foliage insects	Open nest	Beal 1910, Dawson 1923, Van Dersal 1940, Grinnell and Miller 1944, Bent 1946, Martin and others 1951, Root 1967

Table 1--Breeding bird species associated with California habitats in which oaks (*Quercus* spp) comprise a substantial part of the canopy. (continued).

Species	Habitat selection[1]		Breeding censuses[2]					Oaks used for...		References[3]
	Rank	Preferred type	A	B	C	D	E	Food	Nesting	
Yellow-billed Magpie (*Pica nuttalli*)	1	Savannah				33	6	Acorns[a]	Open nest	Dawson 1923, Lindsdale 1937, Van Dersal 1940, Grinnell and Miller 1944, Bent 1946, Barrett and others[5]
Common Raven (*Corvus corax*)	7	Cliffs, grassland	25			33	12	Acorns[a]	Open nest (rare)	Dawson 1923, Barrett and others[5]
Common Crow (*Corvus brachyrhynchos*)	2	Riparian woodland			20	33	12	Acorns[b]	Open nest	Dawson 1923, Van Dersal 1940, Grinnell and Miller 1944, Bent 1946, Martin and others 1951
Mountain Chickadee (*Parus gambeli*)		Subalpine forest						Acorns[b], foliage insects	Secondary cavities	Van Dersal 1940, Grinnell and Miller 1944, Bent 1946, Martin and others 1951
Chestnut-backed Chickadee (*Parus rufescens*)	3	Coastal forest	100	60			41	Bark & foliage insects	Secondary cavities	Grinnell and Miller 1944, Bent 1946, Dixon 1954, Root 1964, Hertz and others 1976
Plain Titmouse (*Parus inornatus*)	1	Oak woodland	25	80	80	100	71	Acorns[d], bark and foliage insects	Secondary cavities	Dawson 1923, Van Dersal 1940, Grinnell and Miller 1944, Bent 1946, Martin and others 1951, Dixon 1954, Root 1964, 1967
Bushtit (*Psaltriparus minimus*)	1	Oak woodland	75	60	100	100	82	Foliage insects	Suspended "sock"	Grinnell and Miller 1944, Bent 1946, Root 1967, Hertz and others 1976
White-breasted Nuthatch (*Sitta carolinensis*)	2	Montane forest		40	40	100	41	Acorns[e], bark insects	Secondary cavities	Van Dersal 1940, Grinnell and Miller 1944, Bent 1948, Martin and others 1951, Verner[7]
Pygmy Nuthatch (*Sitta pygmaea*)		Montane forest	50				12			
Brown Creeper (*Certhia familiaris*)		Subalpine forest	50	20			18	Bark insects	Natural cavities under bark scales	Dawson 1923, Grinnell and Miller 1944
Wrentit (*Chamaea fasciata*)		Chaparral	75	40	40		41	Foliage insects	Open nest	Mailliard 1902, Dawson 1923, Bent 1948
Winter Wren (*Troglodytes troglodytes*)		Coastal forest	100				24			
House Wren (*Troglodytes aedon*)	1	Oak woodland		80	80	33	53	Foliage insects	Secondary or natural cavities	Grinnell and Miller 1944, Root 1967
Bewick's Wren (*Thryomanes bewickii*)	4	Chaparral	100	60	100	67	82	Foliage insects	Natural cavities	Root 1967, Verner[7]
Cactus Wren (*Campylorhynchus brunneicapillus*)		Desert scrub			20		6			
Cañon Wren (*Catherpes mexicanus*)		Inland cliffs			20	33	12			
Mockingbird (*Mimus polyglottos*)	1	Savannah		20	20	33	18	Foliage insects	Open nest	Dawson 1923
California Thrasher (*Toxostoma redivivum*)		Chaparral		20	20	33	18	Acorns[c]	Open nest	Dawson 1923, Van Dersal 1940, Martin and others 1951
American Robin (*Turdus migratorius*)		Montane forest	75	40		33	35	Foliage insects	Open nest	Ritter[6]
Hermit Thrush (*Catharus guttata*)		Subalpine forest	50	20			18	Acorns[a]	Open nest	Van Dersal 1940, Bent 1949, Barrett and others[5]
Swainson's Thrush (*Catharus ustulata*)		Riparian woodland	75	20	20		29			
Western Bluebird (*Sialia mexicana*)	1	Oak woodland	25		60	33	24	Mistletoe berries, perch for hawking	Secondary cavities	Bent 1949, Verner[7]
Golden-crowned Kinglet (*Regulus satrapa*)		Coastal forest	25				6			
Blue-gray Gnatcatcher (*Polioptila caerulea*)	1	Oak woodland		20	20	33	18	Foliage & twig insects	Open nest	Dawson 1923, Bent 1949, Root 1967, 1969

Table 1--Breeding bird species associated with California habitats in which oaks (*Quercus* spp) comprise a substantial part of the canopy. continued.

Species	Habitat selection[1]		Breeding censuses[2]					Oaks used for...		References[3]
	Rank	Preferred type	A	B	C	D	E	Food	Nesting	
Phainopepla (*Phainopepla nitens*)	2	Desert scrub			20	33	12	Mistletoe berries, perch for hawking	Open nest	Dawson 1923, Bent 1950, Walsberg 1977
Loggerhead Shrike (*Lanius ludovicianus*)	1	Savannah				33	6		Open nest	Bent 1950
Starling (*Sturnus vulgaris*)		Riparian woodland		20	60	100	41	Acorns[b], foliage insects	Secondary cavities	Van Dersal 1940, Barrett and others[5], Verner[7]
Hutton's Vireo (*Vireo huttoni*)	1	Oak woodland	100	100	40	33	71	Foliage & twig insects	Open nest	Dawson 1923, Bent 1950, Root 1967
Solitary Vireo (*Vireo solitarius*)	2	Montane forest		80			24	Foliage insects	Open nest	Dawson 1923, Grinnell and Miller 1944
Warbling Vireo (*Vireo gilvus*)	2	Riparian woodland	100	40	20	33	47	Foliage insects	Open nest	Bent 1950, Root 1967
Orange-crowned Warbler (*Vermivora celata*)	2	Chaparral	75	80	60		59	Foliage insects	Open nest	Bent 1953, Root 1967
Nashville Warbler (*Vermivora ruficapilla*)	2	Montane forest						Foliage insects		Bent 1953
Yellow Warbler (*Dendroica petechia*)		Riparian woodland			40		12	Foliage insects		Root 1967
Yellow-rumped Warbler (*Dendroica coronata*)		Subalpine forest	25				6	Foliage insects		Bent 1953
Black-throated Gray Warbler (*Dendroica nigrescens*)	1	Oak woodland	25				6	Foliage insects	Open nest	Dawson 1923, Grinnell and Miller 1944, Bent 1953, Root 1967
Yellow-breasted Chat (*Icteria virens*)		Riparian woodland			20		6			
Wilson's Warbler (*Wilsonia pusilla*)		Riparian woodland	75	20	20		29			
Western Meadowlark (*Sturnella neglecta*)		Grassland			20	67	18	Acorns[b]		Barrett and others[5]
Hooded Oriole (*Icterus cucullatus*)	2	Riparian woodland						Foliage insects		
Northern Oriole (*Icterus galbula*)	2	Riparian woodland		20	80	33	35	Foliage insects	Pendant nest	Dawson 1923, Grinnell and Miller 1944, Bent 1958, Newman and Duncan 1973
Brewer's Blackbird (*Euphagus cyanocephalus*)	1	Savannah				33	6		Open nest	Dawson 1923, Newman and Duncan 1973
Brown-headed Cowbird (*Molothrus ater*)	4	Riparian woodland	50		40	67	29			
Western Tanager (*Piranga ludoviciana*)	4	Montane forest		20			6		Open nest	Bent 1958
Black-headed Grosbeak (*Pheucticus melanocephalus*)	2	Riparian woodland	50	60	60	33	53	Catkins, foliage insects	Open nest	Bent 1968
Lazuli Bunting (*Passerina amoena*)		Chaparral		40			12	Foliage insects	Open nest (rarely)	Dawson 1923, Bent 1968
Purple Finch (*Carpodacus purpureus*)	3	Coastal forest	100	60	20		47	Acorns[a], foliage insects	Open nest	Dawson 1923, Van Dersal 1940, Bent 1968, Barrett and others[5]
House Finch (*Carpodacus mexicanus*)	1	Savannah		20	100	67	47	Foliage insects	Open nest, secondary cavities	Dawson 1923, Bent 1968
Pine Siskin (*Carduelis pinus*)		Subalpine forest	50				18	Foliage	Open nest	Bent 1968
American Goldfinch (*Carduelis tristis*)		Riparian woodland	75				18	Acorns[a]	Open nest (uncommon)	Grinnell and Miller 1944, Barrett and others[5]
Lesser Goldfinch (*Carduelis psaltria*)	1	Savannah		20	80	67	41		Open nest	Dawson 1923
Lawrence's Goldfinch (*Carduelis lawrencei*)	1	Oak woodland			40		12	Oak gall insects	Open nest	Dawson 1923, Grinnell and Miller 1944, Bent 1968
Rufous-sided Towhee (*Pipilo erythrophthalmus*)	5	Chaparral	100	100	100	33	88	Acorns[c], foliage insects		Van Dersal 1940, Martin and others 1951, Davis 1957, Bent 1968

Table 1--Breeding bird species associated with California habitats in which oaks (*Quercus* spp) comprise a substantial part of the canopy. (continued).

Species	Habitat selection[1]		Breeding censuses[2]					Oaks used for...		References[3]
	Rank	Preferred type	A	B	C	D	E	Food	Nesting	
Brown Towhee (*Pipilo fuscus*)	2	Chaparral	50	80	100	67	76	Acorns[a], foliage insects	Open nest	Davis 1957, Bent 1968, Rothstein[9]
Rufous-crowned Sparrow (*Aimophila ruficeps*)		Chaparral		20	20	33	18	Foliage insects		Bent 1968
Dark-eyed Junco (*Junco hyemalis*)	5	Subalpine forest	50	100	40		53	Foliage insects		Root 1967
White-crowned Sparrow (*Zonotrichia leucophrys*)		Chaparral	25				6		Open nest in scrub oaks	Bent 1968
Chipping Sparrow (*Spizella passerina*)	3	Montane forest	25				6	Foliage insects		Root 1967
Song Sparrow (*Melospiza melodia*)		Riparian woodland	50	20	40		29	Foliage insects		

[1] Habitat types classified and ranked by Miller (1951) according to bird species preferences. If no number is entered in the "rank" column, it indicates that Miller did not consider the species to show any preference for oak woodland or savannah.

[2] Percent of sites where each species was recorded during the breeding season; values underlined indicate breeding detected. A = Coastal Marin Co., 4 sites, 8 counts; B = San Francisco Bay Area, 5 sites, 10 counts; C = South Coastal Area, 5 sites, 8 counts; D = Central Valley Area, 3 sites, 7 counts; E = All sites combined. Sources: Hutchinson and Hutchinson (1944, 1945, 1946, 1947), Pugh (1956, 1961), Shepard (1962, 1963), Cogswell (1966, 1973), Robert (1966), Perrone (1970), Remsen (1971), Tangren (1971, 1972), Koenig (1972), Manolis (1972, 1974), Stewart (1972a, 1972b, 1973a, 1973b, 1974, 1975, 1977), Steiker and Maas (1973), Winkler (1973), Bontrager (1974), McKinnie (1974), Loveless and Loveless (1977). In addition, two counts done in 1978 in digger pine/blue oak woodlands in Madera County have been included in the Central Valley Area data (J. Verner and L. V. Ritter, unpubl.).

[3] References pertain to food habits or to nest sites, or both.

[4] Designate proportions of the species' annual diets comprised of acorns, as follows: a = undetermined proportion, b = 0.5 to 2 percent, c = 2 to 5 percent, d = 5 to 10 percent, e = 10 to 25 percent, f = 25 to 50 percent, g = greater than 50 percent.

[5] Barrett, R. H., J. W. Menke, M. E. Fry, and D. Mangold. 1976. A review of the value of hardwoods to wildlife in California with recommendations for research. Final report, submitted to Tahoe National Forest, USDA Forest Serv. Unpubl. typescript. 45 p.

[6] Personal communication. Lyman V. Ritter, PSW Forest and Range Experiment Station, Fresno, (March, 1979).

[7] Personal observations of the author. San Joaquin Experimental Range, Madera Co., Spring, 1978.

[8] Personal communication. Stephen H. Ervin, Calif. State Univ., Fresno, (March, 1979).

[9] Personal communication. Stephen I. Rothstein, Univ. of Calif., Santa Barbara, (March, 1979).

were observed on 15 of 17 sites (88 percent) and in all four zones--Coastal Marin County, San Francisco Bay Area, South Coastal Area, and Central Valley Area (table 1). Fourteen other species were observed in all four zones. These are, in descending order of percent of sites where seen, Anna's hummingbird, bushtit, Bewick's wren, mourning dove, scrub jay, brown towhee, California quail, plain titmouse, Hutton's vireo, acorn woodpecker, red-shafted flicker, black-headed grosbeak, warbling vireo, and downy woodpecker. Certainly these are among the most ubiquitous of the species that utilize oak habitats. Twenty-seven species were observed in three of the four zones, and another 21 were recorded in two zones.

DENSITIES OF BIRD SPECIES FOUND IN OAK HABITATS

Management options ideally should consider densities of animal populations that are subject to management activities. The breeding bird censuses (table 1) used the "mapping method," approved by the National Audubon Society and designed to estimate densities of bird populations. One source of bias affecting these estimates, however, is that of individual pairs of birds whose territories overlap the boundary of the study plot. Seldom are overlapping territories mapped out completely, although some value is assigned to them in computing total density of any given species on the plot. The effect of this bias decreases with increasing numbers of territories that are completely within the boundaries of the plot. The bias is exaggerated, therefore, by decreasing plot size, and by large mean territory size in relation to plot size, for any given species. Both effects should influence estimated densities in breeding bird censuses cited (table 1), because some plots were as small as 8.0 acres (3.24 ha), and many bird species breeding in California oak woodlands have territories larger than that.[7]

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[4] Page, D. J. 1970. San Joaquin River rookery study. Special wildlife investigations report. Project W-54-R-2, Calif. Dep. Fish and Game. Unpubl. typescript. 9 p.

[5] Wilburn, J. W. 1970. Lincoln great blue heron rookery study. Special wildlife investigations report. Project W-54-R-2, Calif. Dep. Fish and Game. Unpubl. typescript. 20 p.

[6] Personal communication. Stephen H. Ervin, California State University, Fresno (March 1979).

The possibility of bias in the censuses cited here was tested by regression analysis (fig. 1). Estimated total densities of breeding birds, as a function of plot size, were fitted to linear, exponential, and power curve regression models. Statistically significant ($P < 0.001$) negative correlations were found in each case: linear model, -0.80; exponential model, -0.81; power curve model, -0.80. The best fit to the data, therefore, cannot be judged by the correlation coefficient. By visual inspection, the power curve fit is the best fit to the data points (fig. 1).

This analysis suggests that estimated breeding bird densities reported in the censuses used (table 1) probably are subject to substantial bias from plot size variation. Reducing plot size from 32 to 8 acres (13 to 3.2 ha), for example, would inflate estimated bird densities by about 2.7 times. Calculated extrapolation of the curve (fig. 1) shows some tendency for the curve to flatten out as the plot size approaches 50 acres (20 ha), but even plots as large as 32 acres are too small to escape the bias.

The curve (fig. 1) suggests that total density of territorial males in California oak woodlands during the breeding season probably is on the order of 1295 per square mile ($500/km^2$). Estimated density by species, however, is beyond the scope of this paper. We need further analyses of the effects of plot size and other variables that can influence density estimates. We also need samples from more sites in each of the various, identifiable types of oak habitats in California, so that each type can be analyzed individually.

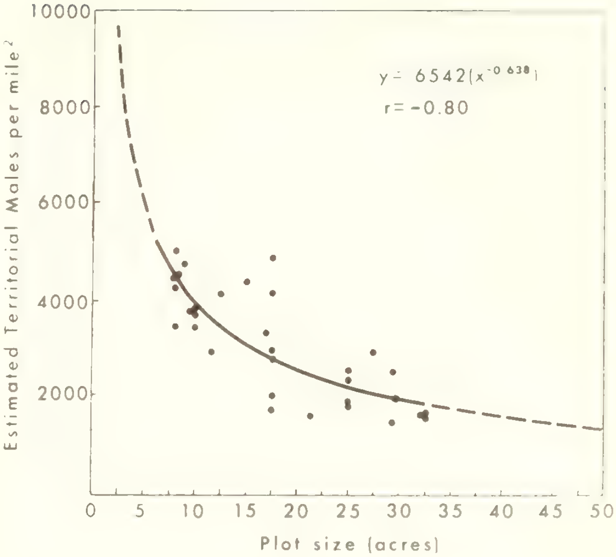

Figure 1--Relationship between plot size and estimated density of territorial males, as calculated from breeding bird censuses (table 1). Dashed portions of the curve are calculated extrapolations from the data.

HOW BIRDS USE OAKS

Oaks are used by birds for feeding and nesting. They also provide elevated perches for resting, surveillance of territory, or watching for prey. Of all the species listed (table 1), at least 30 include acorns in their diet, and at least 45 obtain insects from oak foliage, twigs, bark, or wood. Nine species catch aerial insects by launching from perches in oaks, at least three eat sap, and at least two consume significant quantities of berries from mistletoe growing on oak trees. The list identifies 49 species that build open-cup nests in oaks, two that build suspended nests, six that excavate their own nest cavities, and 20 that use natural cavities or cavities excavated by other species. Altogether the list specifies feeding or nesting uses of oaks for 91 different species of birds (82 percent of the total). No doubt many of the remaining species also use oaks, but because many writers omit reference to the kinds of trees used for feeding or nesting, this information is not available. Moreover, the data on use of oaks were derived from only a partial survey of the literature and personal knowledge. Several species indirectly derive value from oaks. Hawks and owls, for example, consume many prey species that obtain food or nesting cover from oaks, or both.

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[7] Personal observation of the author. San Joaquin Experimental Range, Madera County, Spring 1978.

A general overview such as this unfortunately does not quantitatively assess avian use of oaks. We have little information on the details of foraging by birds in oaks, although proper management of oak stands for birds requires that we know which oak species are most important to foliage gleaners (species that pick insects from foliage surfaces), bark feeders, and others, and whether or not seasonal variations affect species' preferences. We need to know more about bird preferences for acorns of different oak species, and the quantity of acorns consumed by birds in various California oak types. We need to know preferred nest trees, either for open or cavity nesters, and what characteristics tend to make an oak of a given species better for excavation of nest cavities. All of these areas are fertile for research into how we might better incorporate the needs of birds into management plans for oaks.

Although the literature on details of the ecology of birds in relation to oaks is meagre, some outstanding exceptions exist. Two examples are briefly mentioned here, because they set the standard of quantitative excellence we should seek in future studies of bird species and bird communities in California oaks. The first example considers a single species, the acorn woodpecker, which is probably the most oak-dependent bird in North America and one that has received considerable attention from students of avian biology. The second example involves analysis of a portion of an avian community, specifically the foliage gleaners in a coastal oak forest in Monterey County.

The Acorn Woodpecker

Acorn woodpeckers have been studied in detail in California (Ritter 1938, MacRoberts and MacRoberts 1976). Only selected portions from the MacRoberts' study are mentioned here, as these relate more directly to the kinds of questions addressed in preparing management guidelines. Unless otherwise cited, the data used here are from MacRoberts and MacRoberts (1976).

Acorn woodpeckers are highly social birds, forming cooperative groups ranging in size from two to 15 individuals (mean between five and six) at the Hastings Natural History Reservation, Monterey County. An area of about 4.25 square miles (11 km^2) supported 50 to 60 such groups, yielding a rough estimate of 71 birds per square mile ($28/km^2$). This number did not vary much during the MacRoberts' four seasons of study.

Members of a group, except young fledglings, collectively defended the group's all-purpose territory, which usually was occupied permanently, and which ranged in size from 8.7 to 22.2 acres (3.5 to 9 ha). "Territory size is probably determined by the nutritional requirements of the group...(as) it correlated with group size." When the acorn crop failed within a group's territory, the group abandoned its territory.

The birds bred cooperatively, each group typically having only one active nest at a time within its territory. The majority of group members participated in incubation, brooding, and feeding young. Yearlings were less attentive at the nest than were older birds. "At Hastings the reproductive rate was between 0.2 and 0.3 young fledged per adult per year. Only about 60% of the groups breed and only about 40% of the groups fledged young." About half of the fledged young disappeared within their first year, and most of these losses were probably attributable to hawks.

Nestling diet consisted almost exclusively of insects, although acorns comprised the major share of the diet of acorn woodpeckers during most of the year (fig. 2). The acorn woodpecker is best known for its fascinating acorn storing behavior. Acorns of all oak species were used. The birds excavated storage holes just large enough to house one acorn each, concentrating the holes in "granaries" consisting of large, living or dead trees. A sample of 26 groups at Hastings averaged about 4100 functional storage holes in their granaries, with a maximum of about 11,000. Granaries there averaged 2.1 per group, with a range from one to seven. Eighty-eight were located in valley oaks (Quercus lobata), 17 in blue oaks (Quercus douglasii), five in California sycamores (Platanus racemosa), two in black oaks (Quercus kelloggii), and one in willow (Salix spp.). Granary trees were measured (table 2). Utility poles and fence posts also were used occasionally, and other types of granary trees have been reported in the literature, including pines (Pinus spp.), true firs (Abies), redwoods (Sequoia sempervirens), and eucalyptus (Eucalyptus spp.). Ritter (1938) suggested that almost any dead tree, tree with deep dry bark, or building was selected as a granary.

Gutierrez and Koenig (1978) analyzed characteristics of acorn woodpecker granary trees in two California pine-oak woodlands. They reported that each group territory always included at least one main storage tree and "often one or more secondary storage trees. They prefer pines but use oaks where pines are scarce." Storage trees usually were dead or dying. "When initially selected, granary trees

Table 2--Dimensions of trees used as granaries by acorn woodpeckers at Hastings Reservation, Monterey County (from MacRoberts and MacRoberts 1976)[1]

	D.B.H.		Height	
	Mean	Range	Mean	Range
	Inches		Feet	
Valley oak	39.0 (99)	11.0 to 60.2 (28 to 153)	47.6 (14.5)	7.9 to 78.7 (2.4 to 24.0)
Blue oak	25.6 (65)	11.0 to 35.4 (28 to 90)	37.7 (11.5)	10.2 to 60.0 (3.1 to 18.3)
Sycamore	29.1 (74)	14.2 to 50.4 (36 to 128)	53.8 (16.4)	31.5 to 78.7 (9.6 to 24.0)
Black oak	24.4 (62)	18.9 to 29.9 (48 to 76)	44.3 (13.5)	39.4 to 49.2 (12.0 to 15.0)
Willow	19.7 (50)		39.4 (12.0)	

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[1] Values in parentheses are centimeters for D.B.H. and meters for height.

are often living, but because they are the largest and often the oldest trees in the area they are likely to contain rotten limbs in which roosts as well as storage holes can easily be drilled. Such a tree is also likely to die before its neighbors, thus providing the birds with additional storage space and increasing the percentage of dead storage trees in use at any one time."

Gutierrez and Koenig took several measurements from trees in nine group territories at Plaskett Ridge and ten at Cone Peak, Monterey County. Their measurements included all storage trees and the largest nonstorage pine tree in each group's territory. They concluded that "the woodpeckers select the largest tree in a given area" as their primary granary. "Such a choice not only provides the most space for storage holes to be drilled.., but also locates the granaries either in open areas or (as in pine-oak woodlands) above the surrounding canopy; acorn woodpeckers are rarely found in areas which do not provide such openness."

Acorn woodpeckers also eat significant quantities of sap from about early February through early September (fig. 2), drilling holes in selected oaks specifically for gathering sap. "Each group has within its territory several localized areas where borings are made. The same holes are used each year with a few new ones added. Sap hole construction is a communal affair and all members of the group use them." All oak species in the Hastings Reservation study area were exploited for sap.

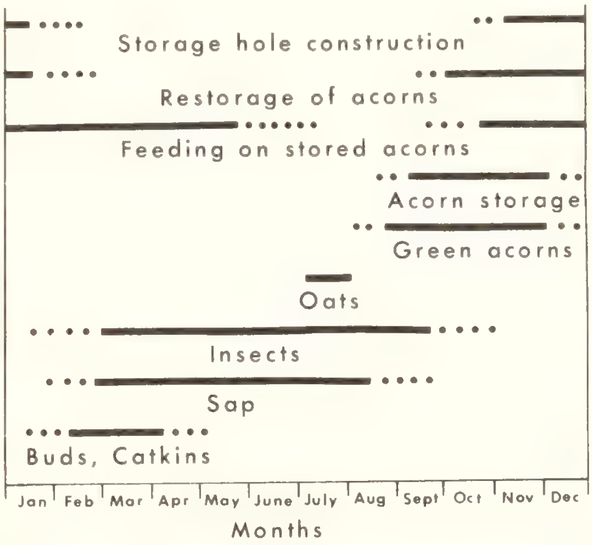

Figure 2--Annual food cycle of acorn woodpeckers at Hastings Reservation (adapted from MacRoberts and MacRoberts 1976).

Acorn woodpeckers also consume significant numbers of insects, mainly in spring and summer. Beal (1911) and Neff (1928) found 23 percent insects in stomach samples of acorn woodpeckers taken at all times of the year. Insects are captured mainly by flycatching, as these woodpeckers rarely glean insects from wood or foliage surfaces or bore into wood to obtain subsurface insects. Minor amounts of other foods are eaten, such as oat seeds, oak catkins, fruit and, perhaps also, leaf buds and pistillate flowers. Grit is consumed daily and often comprises a significant portion of the stomach contents.

These studies of the acorn woodpecker provide the kinds of facts needed in management. Population densities are estimated; general biology is outlined; food resources are identified (quantitative data are given in Beal [1911] and Neff [1928]); and characteristics of trees selected for acorn storage are discussed. At the community level, management requires many of the same details. The study by Root (1967) of foliage-gleaning species at Hastings Reservation gives useful details about the food resources of several bird species and limited information on population densities. Root's paper is possibly the best community-level analysis in California oak woodlands.

The Foliage-gleaning Guild

Root (1967) defines a guild "as a group of species that exploit the same class of environmental resources in a similar way." A guild groups together species that are not necessarily closely related taxonomically. Members of a guild overlap in one or more dimensions of their ecologic niche. The species Root studied in oak woodlands at Hastings all spent significant amounts of time picking insects from surfaces of oak leaves or bark, or both. "To be considered a member of the foliage-gleaning guild in the oak woodland, the major portion of a bird species' diet had to consist of arthropods obtained from the foliage zone of oaks" (Root 1967).

Five species identified as members of the guild during the breeding season were the plain titmouse--but it barely met Root's criteria for this guild, because such a large proportion of its food consisted of "plant material and arthropods living on bark,"--the blue-gray gnatcatcher, Hutton's vireo, warbling vireo, and orange-crowned warbler. Other foliage-gleaners occasionally foraged in the oaks adjacent to their preferred chaparral or riparian sites. Included in this group were the bushtit, black-throated gray warbler, and yellow warbler. Scrub jays, house wrens, Bewick's wrens, dark-eyed juncos, and chipping sparrows, typically ground feeders, also occasionally foraged in oak foliage.

The blue-gray gnatcatcher, warbling vireo, and orange-crowned warbler migrated from the Hastings Reservation for the winter. The resident plain titmouse and Hutton's vireo were joined in the foliage-gleaning guild for the winter months by ruby-crowned kinglets and yellow-rumped warblers. Root's quantitative analysis of the foraging activities of the guild was confined to the breeding season. A section of his study area covering about 70 acres (28.3 ha) had seven pairs of plain titmice, ten to eleven pairs of blue-gray gnatcatchers (based on maps for May 1 and June 27, 1963), two pairs of Hutton's vireos, four pairs of warbling vireos, and four pairs of orange-crowned warblers.

All five species subsisted primarily on insects of the orders Hemiptera, Coleoptera, Lepidoptera, and Hymenoptera, and all regularly foraged in both deciduous and live oaks. Only the plain titmouse "regularly fed upon plant material: seeds and plant fragments were found in 13 of the 16 stomachs examined."

Foraging maneuvers were gleaning (prey resting on substrate, bird standing on a perch), hovering (prey resting on substrate, bird in the air), and hawking (both prey and bird in the air). In terms of foraging strategies, the plain titmouse and the orange-crowned warbler were nearly identical (fig. 3). The two vireo species were very similar, but the blue-gray gnatcatcher stood apart from the other two species pairs. The pairs, however, were not similar in preferred foraging substrates (table 3) and prey selection (table 4). Foraging niches among members of the same foraging guild were diversified, as we see in this example, and, in ecological studies, this is the rule rather than the exception. This sort of diversification is thought by many ecologists to result from interspecific competition, although this is a debated issue. The fact that concerns us here, however, is that, as a result of diversification, birds harvest insects and other invertebrates from all or nearly all of their refugia in any given ecosystem, whether it be an oak woodland or a marsh.

The two studies summarized here highlight some of the kinds of information--population densities, feeding habits, and nesting habits--needed to effectively manage California oak habitats for maintenance of avian communities. More importantly, however, Root's (1967) study of the foliage-gleaning guild at Hastings Reservation provides a way of looking at animal communities that can substantially facilitate their management. The guild approach allows us to group species according to commo ecologic requirements, so it should be possible to identify indicator species for each of the various guilds distinguishable in the animal community. The orange-crowned warbler may be a suitable indicator for the foliage-gleaning guild at Hastings Reservation, for example, because more than 90 percent of its foraging attacks are directed at the foliage. It might even be a good indicator for bark feeders, because maintenance of plenty of foliage will necessarily include maintenance of bark. By assuring that populations of the indicator species are being properly maintained, the manager may be reasonably assured that guild associates of those indicator species are also doing well, and the management task is simplified.

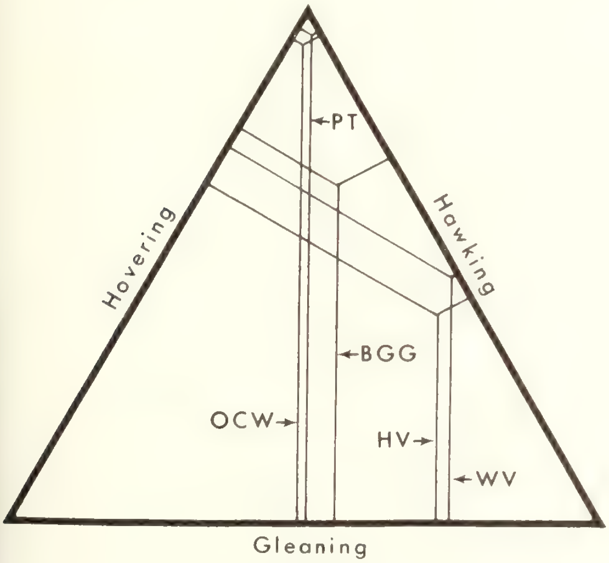

Figure 3--Foraging maneuvers of birds in the foliage-gleaning guild in oak woodlands at Hastings Reservation (PT--plain titmouse, BGG--blue-gray gnatcatcher, HV--Hutton's vireo, WV--warbling vireo, OCW--orange-crowned warbler). The length of each arm of the coordinates is in direct proportion to the percentage of each species' use of the three designated foraging tactics (adapted from Root 1967).

EFFECTS OF BIRDS ON OAKS: A NEGLECTED AREA

Virtually no systematic studies have been done on the effects of birds on California oaks. On the positive side, a few bird species store acorns for later consumption by burying them, usually singly, in widely scattered spots. Griffin (1971, 1976) reported that scrub jays, Steller's jays, and yellow-billed magpies bury large numbers of acorns at the Hastings Reservation, and Baptista[8/] believes plain titmice also may bury some acorns. Many of these acorns, however, are never recovered by the birds and later may germinate. The actual significance of this behavior in maintaining oak stands is totally unknown, although Grinnell (1936) discussed the potential significance of birds as up-hill planters of oaks.

Because birds consume insects, damage to trees by insects may be reduced. Literature that relates this point specifically to California oaks is not available. Studies in other timber types are available, however, and many of these have been summarized by Wiens (1975) and DeGraaf (1978). The general conclusion is that birds probably do not control insect populations or even suppress serious outbreaks of damaging insects once such outbreaks are in full swing. The main effect may be the prevention of serious outbreaks (DeGraaf 1978).

Possible negative effects of birds on oaks also have been neglected by researchers. Birds consume mistletoe berries and probably disperse the parasite in their feces. Excavation of oaks by birds for insects, nest cavities, acorn storage holes, or sap collecting holes probably increases tree vulnerability to invasion by pathogens and insects. Oaks and birds, however, have coexisted for millions of years, so it is difficult to imagine that these negative effects need give us much cause for concern. Nevertheless, research needs to be done to assess possible negative effects of birds on oaks.

MANAGEMENT CONSIDERATIONS

Effective management of California's oak habitats must provide for the rich avifaunas associated with them. We need to know how avian communities respond to various manipulations of oak habitats. Limited research in this field has been done in the Eastern United States, but practically none has been done in the West. Most oak types in the East receive substantially more precipitation than most oak woodlands in California. Moreover, Eastern oaks are managed for timber production on a scale much larger than in California. These facts suggest that we should not apply results of Eastern studies to management of Western oaks.

Oaks provide numerous, varied resources, as discussed so forcefully in this symposium. Priorities among the products and values

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[8/] Personal communication. Luis Baptista, Occidental College, Los Angeles (March 1979).

Table 3--Attacks at various substrates in oak trees during the breeding season by members of the foliage-gleaning guild[1] (from Root 1967)

	Herbs	Twigs	Air	Foliage
Plain titmouse	11.2	47.6[2]	0	41.3
Blue-gray gnatcatcher	0	3.2	13.3	83.5
Hutton's vireo	0	19.6	6.5	73.8
Warbling vireo	0	6.6	1.6	91.8
Orange-crowned warbler	0.6	1.9	0.6	96.9

[1] The foliage-gleaning guild includes all species that obtain a significant portion of their food supply by picking insects from surfaces in the foliage layer.

[2] Includes picking at lichens and fruit.

Table 4--Arthropods in diets of foliage-gleaning species, based on prey identified in stomach samples (from Root 1967)

	Prey identified	Hemiptera	Coleoptera	Lepidoptera	Hymenoptera	Other
	Number	- - - - - - - - - - - -	- - - -	Percent	- - - - - - - - - - - -	
Plain titmouse	81	13.2	55.3	6.5	10.2	14.8
Blue-gray gnatcatcher	287	36.0	32.3	7.1	13.8	10.8
Hutton's vireo	134	11.9	29.8	24.6	22.4	11.2
Warbling vireo	213	10.3	15.0	62.0	6.6	6.1
Orange-crowned warbler	46	47.8	6.5	37.0	4.3	4.3

associated with oaks must be established and clearly stated in plans for any given management unit. That is, goals must be set. It is not my purpose to build a case for managing all our oak habitats for maximum benefit of birds, although this may be a selected goal in some instances. Rather, I believe that negative effects on all resources, including birds, should be minimized whenever we choose to manipulate our native environments in any manner.

Provision for birds in managed oak stands requires that sufficient numbers of trees be available to supply the foraging, nesting, perching, and cover needs of birds in the community. Especially important also is that there be enough acorns. I believe, however, that we tend to overemphasize management of oaks for acorn production as wildlife food, forgetting that oaks provide important habitats for more bird species that do not depend on acorns than for species that do. Proper timing of project activities on a management unit also is important because of the annual cycles of birds and the regeneration capabilities of oaks.[9] Management must also concentrate on foraging and nest site requirements of birds, as adequate provision of these needs most likely will provide adequate perches and cover for birds in our oak woodlands.

Foraging Requirements

Birds find food on all parts of oaks--the trunks, branches, twigs, buds, flowers, and foliage. The full spectrum of potential foraging substrates is best provided by mixed-species, uneven-aged stands. Live oaks particularly should be maintained in those stands now containing them, as they provide foliage for cover and as an important foraging substrate for many species during the winter months.

Reid and Goodrum (1957) suggest the need to provide suitable oaks of mixed ages within the home ranges of species using them. Because some bird species in California oak woodlands may have territories as small as 2 or 3 acres, a properly managed stand should have a continuing supply of oaks suitable to birds on every 1- or 2-acre parcel. In some instances, however, even widely scattered trees in savannah habitats may meet the nesting requirements for several pairs of the same species, particularly ground feeders that nest in trees. Rothstein,[10] for example, reported finding single oaks near Shandon, San Luis Obispo County, with three or four northern oriole nests and several nests of Brewer's blackbirds. "On the other hand, the only tree in such areas may consistently have a western kingbird nest, but only one."

Mistletoes that parasitize oaks supply berries as an important source of food for some species, most notably the phainopepla. Control of mistletoe in oaks may be vital to maintaining tree vigor, but complete elimination of mistletoe could have a significant negative effect on populations of at least a few bird species. Some compromise may be necessary.

Acorn Consumption

Acorn consumption by birds in California oak habitats has not yet been quantified adequately, partly because we lack suitable estimates of the densities of bird species that eat acorns, and partly because we lack accurate figures on the weight of acorns normally consumed by various species during a year. Several researchers have attempted to estimate minimum acorn needs for wildlife (including mammals as well as birds) in Eastern and Southeastern oak forests. Shaw (1972) summarized this work, and concluded that about 100 lb per acre (112 kg/ha) of acorns "(total tree-crown production) is a reasonable goal when acorn-consuming game and nongame species are considered." Whether or not this value is a realistic ball-park figure for California habitats is not known. As in many of the Eastern studies, however, wildlife in California's oak habitats have been observed to remove all acorns from traps even in heavy production years (Griffin 1976). This heavy use of acorns suggests that the needs of animals in the West may not be too different from those in the East.

If this is true, then, we may next ask whether or not managers can reasonably set a goal of producing an annual yield of acorns for wildlife at 100 lb per acre in California's oak woodlands. Recent studies by the California Department of Fish and Game[11] show that acorn production on that order of magnitude probably is a modest expectation, on most sites at least. Dry weight yields of fallen acorns in blue oak stands ranged from 9 to 191 lb per acre (10.1 to 214 kg/ha), and in interior live oak (Quercus wislizenii) stands from zero to 97 lb per acre (109 kg/ha). One canyon live oak (Quercus chrysolepis) stand produced 1960 lb per acre (2195 kg/ha), and black oak stands ranged from zero to 1543 lb per acre (1727 kg/ha). Values differed enormously between years on the same site, but further work is needed to adequately characterize this variability. If wildlife consume most or all fallen acorns, even when yields approach 2000 lb per acre, production of 100 lb per acre may not be an adequate goal. Before we accept this value uncritically, it must be thoroughly researched for wildlife in California oak types.

Acorn production by most California oak species is not high every year. Production tends to be high at 2-year, 3-year, or irregular intervals (Sudworth 1908, Wolf 1945). Different species are not necessarily synchronized in the timing of high and low production years. Management to ensure adequate acorn production on any given site, therefore, can be increased by mixed-species stands of oaks.

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[9] Murray, L., J. A. Lorenzana, W. J. Bradley, and W. R. Thornton. 1973. Black oak management plan, Mendocino National Forest. Unpubl. typescript. 23 p.

[10] Personal communication. Stephen I. Rothstein, University of California, Santa Barbara (March 1979).

[11] Graves, W. C. 1976. The dependency of upland game on oak mast production. Progress report on upland game investigations. Project W-47-R-24, Calif. Dep. Fish and Game. Unpubl. typescript. 16 p.

Barrett and others[12] suggest that sources of measured variation in acorn production "probably include at least: 1) tree genetics, 2) trap position under canopy, 3) tree size (crown cover), 4) tree shape (dominance), 5) tree age (DBH), 6) site (plot), 7) regional environment (area), 8) annual weather." At least some of these variables may be incorporated into management planning to increase acorn production. Size and shape of the crowns of more productive trees (genetic differences?, site differences?), for example, might be improved for acorn production by selective removal of appropriate neighboring trees. Stands may be managed to assure a sufficient number of older trees, which tend to be the most productive (Shaw 1972). McDonald (1969) found that black oaks do not produce viable seeds before 30 years of age, and not until they are about 80 years old do they produce acorns in large quantities. High production levels may then be maintained at least to an age of 200 years.

As to acorn consumption, Gutierrez and Koenig (1978) recommend that acorn granary trees be maintained for acorn woodpeckers. This recommendation is not restricted to oaks, because the woodpeckers use other species of trees too. Existing granary trees should be identified and spared whenever tree cutting or removal of any kind is planned. Because the birds apparently prefer the largest trees in an area as granaries, old, large living trees should be spared. "The number of potential storage trees retained in an area should at least be equal to, and preferably located near, snags presently in use as granaries."

Nest Site Requirements

Managing oak stands to provide ample nesting sites for birds suffers presently from a lack of quantitative information on preferred tree species and optimum tree sizes, shapes, and states of decadence. As with adequate provision of foraging substrates and acorn production, maintenance of mixed-species stands is important, because different bird species exhibit different preferences for nest cover. Older, larger trees should be available for cavity nesters, and uneven-aged stands should be planned to provide for replacement of fallen cavity trees. In my experience, snags--dead or partly dead trees--are less critical to cavity nesters in oak woodlands than they are in other timber types; most nest cavities at the San Joaquin Experimental Range, in Madera County, are in living blue oaks.

The Guild Approach

After enough data have been accumulated on the feeding and nesting behaviors of birds in California oak habitats, we should classify the bird species by guilds and take a guild approach to management. The next step is to select suitable indicator species for each guild, and regularly inventory populations of indicator species to determine population trends over long periods of time.

This presupposes suitable inventorying methods for oak habitats. Such methods need to be researched within constraints of providing reliable population trends, if not reliable estimates of densities, and being time and cost efficient. Inventorying should be done before and after all sorts of management treatments in all sorts of oak habitats to assess impacts. Particularly important in this regard may be any activity that affects understory vegetation, especially the shrub layer. Shrubs are required by a number of bird species commonly associated with oaks, so shrub removal may have a large impact on the number of bird species able to use an oak stand.

Consideration of Adjacent and Included Habitats

Plans for management units that include, or are adjacent to, other habitat types must consider the additional bird species such habitats attract. Earlier discussions pointed out that several species of birds regularly exploiting oak habitats do so only because their preferred habitat is available in the area. Twenty species listed in table 1 show first preference for riparian sites and another 14 show first preference for chaparral. These two habitats are frequently associated with oak woodlands in California, and some bird species preferring them are exhibiting downward population trends. The National Audubon Society publishes in alternate years a "Blue List" of species for which available field data indicate declines of a magnitude deserving attention. Those from table 1 that are cited in the 1978 Blue List (Arbib 1977) for the Pacific coastal area are, by preferred habitat type: 1) Riparian woodland - Cooper's hawk, red-shouldered hawk, yellow warbler, and yellow-breasted chat; 2) Savannah - Swainson's hawk; 3) Coastal forest - purple martin.

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[12] Barrett, R. H., J. W. Menke, M. E. Fry, and D. Mangold. 1976. A review of the value of hardwoods to wildlife in California with recommendations for research. Final report, submitted to Tahoe National Forest, USDA Forest Serv. Unpubl. typescript. 45 p.

Summary of Specific Recommendations

Multiple-use management of oak stands likely can accommodate the requirements of birds if all of the following general recommendations are incorporated into the management plans.

- Concentrate on the feeding and nesting requirements of breeding birds, as adequate provision for them will likely satisfy the other needs of birds in oak woodlands--including those of migrants and winter residents.
- Use the guild approach, including selection of suitable indicator species.
- Maintain mixed-species, uneven-aged stands, especially allowing for live oak retention.
- Provide a continuing supply of oaks, generally distributed on every acre or 2-acre parcel of the management unit that presently supports oaks.
- Provide a continuing supply of large, old trees, especially those with a good record of high acorn production.
- Manage for a mean annual production of at least 100 lb of acorns per acre, until further research establishes a better estimate of wildlife's needs.
- Provide an ample shrub layer where one occurs in existing oak stands, and consider the possibility of establishing shrubs in stands from which they were removed in the past.
- Consider needs of oak-using species from different, adjacent habitat types.

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Acorn Storage by Acorn Woodpeckers in an Oak Woodland: An Energetics Analysis[1]

Walter D. Koenig[2]

Abstract: Acorn woodpeckers (*Melanerpes formicivorus*) are a major harvester of acorns throughout California, eating them as they mature and caching them in storage trees each fall. At Hastings Reservation in central coastal California, a population of 120 to 130 birds stored an average of 43,600 acorns (344 per bird) each year. These acorns provide an estimated caloric content of edible material of 180,500 kcal, only about 6 to 7 percent of the total yearly metabolic requirements of the woodpecker population. These data are sufficient to indirectly provide a reasonable estimate of average acorn production in the study area.

The pattern of acorn storage by the acorn woodpecker and other major acorn harvesters in California contrasts with harvesters of piñon pine nuts (primarily Clark's nutcrackers and piñon jays) in the Southwest. Nut storage by both these species apparently results in significant dispersal of seeds, whereas most of the acorn harvesters in California effectively predate the acorns they pick. Equally contrasting are the adaptations of the mast-producing trees in the two communities. Piñon pines exhibit characteristics promoting seed dispersal by birds, while oaks in California do not appear to have evolved comparable mechanisms.

INTRODUCTION

The pattern of energy flow within natural ecosystems can provide useful insights into the factors influencing population dynamics and community organization (Wiens and Innis 1974). Here I present an energetics analysis of one component of the California oak woodland community. The approach I will take is preliminary and limited, but could readily be expanded to include more species in the acorn consumer guild, leading to a more complete evaluation of their impact on oak ecology and population dynamics.

The acorn woodpecker (*Melanerpes formicivorus*) is one of the most characteristic birds of oak and pine-oak woodlands throughout western North America. The birds live in permanently territorial family groups of between two and fifteen individuals; their diet is diverse, including flying and bark-crawling insects, sap, wild oats, fruit, vertebrates, oak buds and flowers, and acorns. They do not bore into wood as do most other woodpecker species. Acorns, which are the single most important item of their total diet, are eaten directly off the trees from the time they ripen in the fall until none remains. In addition, acorn woodpeckers have a unique way of coping with food shortage during the winter. Each group of birds defends a storage tree, or granary, within which acorns are stored individually in holes (MacRoberts and MacRoberts 1976, Gutiérrez and Koenig 1978). Stored acorns are a crucial resource. Not only are birds unable to remain resident on their territories through most winters without access to them, but also reproduction the following spring is impossible for groups whose stores have been exhausted during the winter (Koenig 1978). Acorn woodpeckers are most dependent on acorns during the fall and winter (approximately September to March), but groups with stored acorns remaining continue to use them through the spring and summer.

METHODS

Data were collected as part of a study of the ecology and social behavior of the acorn woodpecker at Hastings Natural History Reservation, Monterey Co., central coastal California. Approximately 25 groups of acorn woodpeckers were banded and censused beginning in fall of 1971, permitting accurate estimates of population size. Between July 1974 and September 1978 the number of stored acorns in each granary at Hastings was counted at bimonthly intervals. Beginning in the winter of 1975-76, I took random samples of stored acorns from accessible sections of each granary. These were identified to species (five are common in the area: *Quercus lobata* Née, *Q. agrifolia* Née, *Q. douglasii* H. & A., *Q. kelloggii* Newb., and

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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Q. chrysolepis Liebm.), dried for several months, shelled, and the cleaned cotyledons weighed. In 1975-76, only the total weight of the acorn sample was taken for each group of acorn woodpeckers. In the other two years acorns were divided first by species and then by degree of insect damage. Each set thus obtained was then weighed separately. These data permitted estimation of the total number and proportion of acorns of each species stored by the woodpecker population, the mean weight of undamaged acorns, and the average amount of insect damage that occurred to stored acorns of each species.

The energy consumption of acorn woodpeckers was estimated from values of existence metabolism (Pimm 1976) corrected for the increased costs of normal activity and digestive inefficiency (Wiens and Innis 1974). The caloric content of acorns was estimated using an average 9.7 kcal/gm for lipid content and 4.2 kcal/gm for the remaining material; average lipid content for acorns of each species are from Tucker[3/]. Estimates of acorn production were gleaned from the literature.

RESULTS

Table 1 lists the estimated total numbers of stored acorns cached by acorn woodpeckers at Hastings for each of the three years. The relative proportion of the total made up by each of the five species of oaks varied considerably from year to year; however, the total number of stored acorns was relatively constant, ranging between 42,000 and 45,000 ($\bar{x}=43,607$), or about 344 acorns/bird/year. Table 2 summarizes the total estimated number of acorns of each species stored, along with the mean weight, amount of insect damage, total weight of stored acorns, caloric content per gram and per acorn for each species, and total caloric content of all stored acorns averaged for all data. After correcting for insect damage, the total average weight of stored acorns was 39 kg/year. In total, the estimated caloric content of stored edible material averaged 180,500 kcal/year.

These values represent the average maximum total energetic content of stores. Maxima were generally counted in December or January when acorn fall was complete. Prior to this, during a period of about four months beginning when acorns first begin to mature, acorns are eaten directly off the trees rather than from the granary (or, alternatively, those taken from the granary are replaced by newly harvested acorns).

The estimated metabolic requirement of the acorn woodpecker population at Hastings was compared with the caloric value of stored acorns (table 3). The proportion of the total metabolic requirement (TMR) of the population accountable in stored acorns is surprisingly low--only 6 to 7 percent. Even considering only the eight months of the year during which acorns are *not* available directly from the trees, stores account for only 10 or 11 percent of their remaining TMR. The relatively constant proportion of the TMR met by stored acorns during the study suggests that this proportion is usually not limited by the acorn supply itself, which varied considerably during the three years[4/].

Table 1 -- Yearly variation in species composition of acorns stored by acorn woodpeckers at Hastings Reservation

Year	Percent of all stored acorns					Total(N)
	Q. agrifolia	*Q. lobata*	*Q. douglasii*	*Q. kelloggii*	*Q. chrysolepis*	
1975-76	5.0	17.0	51.4	18.1	8.4	45470
1976-77	27.1	34.3	15.6	15.2	7.9	41927
1977-78	19.5	50.3	21.6	8.0	0.6	43425
Mean	16.9	33.7	30.0	13.8	5.6	43607

These data are readily convertible to energy flux per unit area. The approximate size of the study area is 247 ha, of which about 70 percent consists of oak woodland or forest in which oaks are common. Thus, given an average TMR for acorn woodpeckers at Hastings of 2,810,000 kcal/year and acorn reserves of 180,000 kcal/year (tables 2 and 3), the mean TMR of the population is about 11,400 kcal/ha/year while the energy stored in granaries amounts to 730 kcal/ha/year. Table 4 lists the percent of total acorn production which would be stored in granaries given these estimates and an acorn crop of four different orders of magnitude. The proportion of the acorn production stored in granaries ranges from a high of 22 percent given a crop of 1 kg/ha to 0.02 percent if the crop were 1000 kg/ha.

Using these values the relationship between acorn production and the TMR of the acorn woodpecker population can also be estimated (table 4). In this case, given an average crop of 1 kg/ha, the TMR of the population would be over three times the total acorn production. Given a crop of 1000 kg/ha, the TMR of the population would be only 0.3 percent of the acorn production.

The actual fraction of the total acorn production which is used by acorn woodpeckers is dependent not only on the production itself but also on the proportion of their diet made up of acorns. Early studies based on stomach content analyses suggested that this proportion might be as high as 50 to 60 percent (Beal 1911, Neff 1928), far higher than the proportion suggested by the data on acorn storage discussed above. However, I feel that these early figures are certainly overestimates, both because of the relatively slow digestive rate for seeds such as acorns compared to other softer material consumed by acorn woodpeckers, thereby biasing stomach content analyses (see Custer and Pitelka 1976), and also because of the difficulty in assessing the importance of sap, a food resource only recently shown to be important for acorn woodpeckers (MacRoberts 1970). If half the diet of the population during the storing months of September to December is made up of acorns and only stored acorns remain after that time, acorns would then make up about 25 percent of their total diet. Then, if the acorn crop averaged 10 kg/ha, woodpeckers would consume approximately 9 percent of the total crop, and less than 1 percent if the crop averaged 100 kg/ha (table 4).

DISCUSSION

Problems in Estimates of Acorn Production

Though each step of this analysis is an approximation, the greatest uncertainty is in the estimation of acorn production

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[3/] Unpublished data; J. Tucker, Dept. Botany, Univ. California, Davis.

[4/] Unpublished data; J. Griffin, Hastings Reservation, Univ. California, Carmel Valley, California.

Table 2 -- Mean weight, insect damage, and caloric content of acorns stored by acorn woodpeckers

	Q. agrifolia	*Q. lobata*	*Q. douglasii*	*Q. kelloggii*	*Q. chrysolepis*	Total
Total number of acorns stored	7,370	14,696	13,082	6,018	2,442	43,607
Mean weight of undamaged acorns (gm)	1.00	1.10	1.06	1.14	1.43	---
Mean percent of cotyledon eaten by insects	17	15	23	17	21	---
Mean edible weight (gm)	0.83	0.93	0.82	0.95	1.13	---
Total weight of stored acorns (kg)	6.10	13.73	10.69	5.71	2.75	38.97
Kcal/gm	5.16	4.44	4.41	5.01	4.51	---
Kcal/stored acorn	4.27	4.15	3.60	4.75	5.08	---
Total caloric content of stored acorns (kcal)	31,500	60,900	47,100	28,600	12,400	180,500

(table 4). Obtaining such estimates is a difficult but essential challenge to future ecologists interested in oak communities. Values reported by Wolf (1945) suggest that in good years acorn production of California oaks may reach 2000-6000 kg/ha wet weight, or about 1300-3500 kg/ha dry weight. More recently, Graves (1976, 1977) reported preliminary values of acorn fall in Sierra foothill communities of 0 to 2200 kg/ha dry weight. At Hastings Reservation, acorn falls of 0 to 98 acorns/m^2 (about 0 to 1100 kg/ha of edible cotyledons) below four valley oaks (*Quercus lobata* Née) over a 9-year period have been recorded[4/].

Table 3 -- Energetic requirements of acorn woodpeckers at Hastings Reservation

	1975-76	1976-77	1977-78
Mean number of birds in the study area	131.6	122.9	126.3
Total metabolic requirements of the population (kcal/year)[1/]	2,910,000	2,720,000	2,790,000
Caloric content of stored acorns (kcal)	214,000	183,000	169,000
Percent of TMR met by stored acorns	7.3	6.7	6.1
Percent of MR met by stored acorns during period when acorns are not available	11.0	10.0	9.8

[1/] Estimated using Pimm's (1976) equation for existence metabolism with a mean body weight of 80 gm, air temperature 13°C, and 13 hr photoperiod. Digestive efficiency was estimated as 70 percent and the cost of normal free ranging activity as 40 percent above existence metabolism.

These data indicate wide variation in production from year to year, species to species, and even from tree to tree. These fluctuations vary over at least two to three orders of magnitude and range up to a maximum of possibly over 1000 kg/ha. It is unlikely, however, that acorn fall would average this high over an area of mixed terrain and habitat covering several hundred hectares such as is of interest here. On the other hand, the values cited are for acorn fall, *after* crown-harvesters have already removed all the acorns they were able to take. Thus, though the range in production values used in Table 4 are probably representative of the variability shown in oak woodlands in California, there is as yet no data with which to estimate the average production over a relatively wide area of any California habitat.

However, the data presented here on the metabolic requirement of the acorn woodpeckers allow a rough estimation of probable average acorn production. If 25 percent of the diet of acorn woodpeckers consists of acorns, a proportion which no doubt varies from year to year but is

Table 4 -- Relation of acorn production to use by acorn woodpeckers

	Mean acorn production (dry weight)			
	1 kg/ha	10 kg/ha	100 kg/ha	1000 kg/ha
Edible production (kcal/ha)[1/]	3,400	34,000	340,000	3,400,000
Percent of production stored by acorn woodpeckers	21.5	2.2	0.22	0.02
TMR of the population divided by total acorn production	3.4	0.34	0.03	0.003

[1/] Estimated using an inedible shell weight averaging 30 percent of dry weight and an average caloric content of 4.8 kcal/gm for cotyledons.

probably a reasonable estimate, the woodpecker population would have to consume 85 percent of a total acorn crop averaging 1 kg/ha. This is clearly unrealistic. At 10 kg/ha, woodpeckers would consume about 9 percent of the total acorn crop, still improbably high but low enough to allow at least a few other acorn consumers to coexist with them. Consideration of the metabolic requirements of these other acorn users, including crown harvesters (other birds and squirrels), ground predators (deer, rats, and mice), and parasites (various insects), would provide an excellent means of estimating total average acorn production.

Contrast of Oak and Piñon Pine Communities

A fascinating comparison of these data is possible with that of Vander Wall and Balda (1977) for the harvesting and caching of piñon pine (*Pinus edulis* Engelm.) by Clark's nutcrackers (*Nucifraga columbiana*) in northern Arizona. These authors estimated that a population of about 150 birds cached between 3,300,000 and 5,000,000 nuts/year, compared to only 44,000 acorns/year stored by the Hastings population of about 125 acorn woodpeckers. The total weight of harvested nuts was calculated to be between 685 and 1028 kg for the nutcrackers compared to only 39 kg for the woodpeckers. Finally, Vander Wall and Balda estimated that each bird stored between 26,000 and 39,000 kcal/year in nuts, 2.2 to 3.3 times the amount of energy needed to survive through the six months of winter during which they eat the seeds. In contrast, each acorn woodpecker stored on the average only 1,420 kcal/year in acorns, only 10 to 11 percent of the MR for the remaining eight months during which acorns are not available in the trees.

These differences suggest that the acorn woodpecker-oak interaction is very different from that of Clark's nutcrackers and piñon pines. Nutcrackers harvest more energy than they need and presumably the recovery rate of seeds they cache is low. Acorn woodpeckers harvest only a fraction of their TMR, invest a great deal in maintenance of these stores, and recover virtually all the material they originally store.

These contrasts are reflected in the life-histories of both the birds and of the trees. In terms of the former, both Clark's nutcrackers and piñon jays (*Gymnorhinus cyanocephalus*), a second major harvester of piñon nuts (Balda and Bateman 1971, Ligon 1978), harvest nuts in large flocks of 100 to 300 birds. Flocks of both species are nomadic and may move long distances to find and store nuts. Recovery rate of cached nuts is low and at least some eventually germinate.

The major crown-harvesting acorn consumers in California follow different exploitation patterns. Acorn woodpeckers, as discussed above, live in relatively small, stable family groups which defend permanent territories. Only if the acorn crop fails entirely within a group's home range do they move elsewhere. Few acorns stored by acorn woodpeckers gain the chance to germinate, though a small number are dropped by the birds prior to being stored in a granary.

Scrub jays (*Aphelocoma coerulescens*) are also territorial and sedentary, though temporary feeding assemblages of 50 or more birds may form in order to harvest acorns from localized areas with heavy crops[5/]. Scrub jays cache acorns in the ground, however, and thus are probably important to acorn dispersal (Grinnell 1936). Three other crown-harvesting acorn consumers in California, Lewis' woodpeckers (*Melanerpes lewis*), band-tailed pigeons (*Columba fasciata*), and common crows (*Corvus brachyrhynchos*), are similar to nutcrackers and pinon jays in that they are nomadic and aggregate into flocks in the fall (Bock 1970, Grinnell *et al.* 1918). However, none of these species store acorns in the ground or in a way likely to result in acorn dispersal.

There also appear to be striking adaptive differences between the oaks and piñon pines. Piñon pines exhibit characteristics which can be interpreted as adaptations for seed dispersal by nutcrackers and piñon jays. Among these characteristics are a high lipid content of seeds (about 60 percent compared to less than 20 percent for acorns), high visibility and distinct seed coloration, relatively large seed size compared to other pines, and synchronized production of seed crops over wide geographic areas (Vander Wall and Balda 1977, Ligon 1978). No comparable coadaptations are evident among California oaks; if anything, the tannins of acorns are likely to have evolved as a deterrent to avian harvest and dispersal. Little investigation has been done on any of these factors in oak communities, however. It would clearly be profitable to examine interspecific variation in acorn size, lipid content, tannin content, and synchrony of acorn production in terms of the potential role of these factors in either promoting or hampering harvest and dispersal.

In conclusion, I wish to emphasize the importance of two factors to the understanding of oak ecology. First is the potential usefulness of an energetics approach, preferrably quantifying the energetic investments and constraints of both producers (the oaks) and consumers (acorn harvesters). Second is the importance of coadaptations between producers and consumers in determining the observed pattern of the energetic investment of the oaks. We cannot understand the ecology of oaks nor manage them intelligently without consideration of the species which live off them and disperse them.

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Quercus kelloggii

Annual Oak Mast Yields from Visual Estimates[1]

Walter C. Graves[2]

Abstract: A method for visually estimating mast yields is described. Results of three years of field testing and application are listed. Practical application of the method for management and research is discussed.

INTRODUCTION

Seventeen species of oaks occur in California. They provide an important element of habitat association for many wildlife species. The annual mast or acorn crop produced by a single species or in combination with associated species contributes significantly to the food supply of wildlife. Dependent species include tree squirrels (*Sciurus griseus*), wild turkeys (*Meleagris galloparo*), band-tailed pigeons (*Columba faseiata*), mountain quail (*Oreortyx picta*), valley quail (*Lophortyx californicus*), wood ducks (*Aix sponsa*), mallards (*Anas Platyrhynchos*), wild pigs (*Sus scrofa*), bear (*Ursus americanus*), deer (*Odocoileus hemionus*), acorn woodpeckers (*Melanerpes formicivorus*), Steller's jays (*Cyanocitta stelleri*), and scrub jays (*Aphelocoma coerulescens*).

Because of the recognized importance of oak associations and acorns to wildlife, the California Department of Fish and Game has been conducting an oak-wildlife relationship study since 1975. The major objective is to develop oak management plans for both public and private lands that provide proper cover and food for wildlife. Similar studies have been reported in other states on other species of oaks (Goodrum et al. 1971).

The first step toward meeting the study objective was to monitor annual acorn production per individual tree and per area. Individual tree production data were to be correlated with physical tree measurements, while area production data was to be correlated with annual changes in selected wildlife species and wildlife population levels. Seed traps (Downs and McQuilkin 1944) were used to obtain initial production data from randomly selected trees. Acorn yield data collected in this manner were extremely variable and led to several modifications in the study (Graves 1977).

One major change was to select sampled trees based on some knowledge of potential to produce acorns. This was accomplished by designing and field testing a method to visually classify acorn production. This paper describes that procedure.

METHODS

1. Four classes for acorn production of individual trees were defined as follows:
    - Class #1 - No visible acorns (Score 1)
    - Class #2 - Acorns visible after very close examination. Maybe only one or two are observed (Score 2)
    - Class #3 - Acorns readily visible, but they do not cover the entire tree and the limbs do not appear to bend from their weight (Score

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Wildlife Biologist, California Department of Fish and Game, Chico, California.

Class #4 - Acorns readily visible and covering the entire tree; limbs appear to sag from weight of acorns (Score 4)

2. Instructions for classifying each individual tree were as follows:

a. Walk up to the tree and note that acorns are either readily visible or not visible.

b. If acorns are not readily observed, the tree is either a Class 1 or a Class 2. Walk around the tree and look for acorns. Use field glasses if necessary. If no acorns are observed, the tree is a Class 1. If one or more acorns are observed, the tree is a Class 2. Record the class on a data sheet and go to the next tree.

c. If acorns are readily observed, the tree is either a Class 3 or 4. Walk around the tree to see if acorns are found all over the tree. If they are well distributed around the tree, the tree is a Class 3. Also, if the acorns are only on one side or in one area, the tree is a Class 3. If the acorns occur in clusters of two, three, or more, all around the tree, it is a Class 4. In this class, the limbs are often bending from the weight of acorns. Record data and go to the next tree.

3. Three or more observers classified the same sample of 150 trees to determine variation between observers.

4. Blue oak (Quercus douglasii) trees on a 60,000-acre ranch were randomly selected(by driving along roads, stopping at .2 mile intervals, and classifying the nearest five trees)and sampled in groups of 100 to determine adequate sample size needed to estimate acorn production for a given area.

5. Visual classes were compared to samples of acorns collected in 0.2 m^2 seed traps to relate the visual classes to some quantitative value. Wire-framed seed traps with burlap sacks were placed under two Class 1, sixteen Class 2, 46 Class 3, and 36 Class 4 trees. The number of trees sampled per class were predetermined from the expected range in dry weight of acorns collected per tree per class, expressed as a percentage of the total expected range for all classes. Physical tree measurements were recorded for each of these sampled trees.

6. Application of the method to obtain trend data for various geographic areas and oak species throughout the state was initially tested in 1976 with continued surveys in 1977 and 1978, using the described classes with the following instructions:

a. Based on your subjective knowledge of oak distribution in your area, select representative area or areas for each oak species. Mast production varies from one slope to another. Therefore, the sample should include trees from various slopes and elevations.

b. Selection of trees should be on a random basis at preselected stops along roads or equal distances along walking transects. Do not select trees because of size, form, or obvious presence of acorns. Trees should be away from roadways to avoid unnatural edge effect.

c. Classify 100 trees of each species per wildlife management unit.

RESULTS

Variation in classifying individual blue oak trees occurred with three observers. They independently classified the same 150 trees, and all three classified 74 percent of the trees the same. Two observers were in agreement on the classification for the remaining 26 percent with the third observer placing the tree one class above or below the other observers. The most frequent discrepancy occurred between Class 1 and Class 2 trees. This variation between observers in individual tree classification became insignificant in the overall average production class for the 150 trees with averages of 2.25, 2.23, and 2.25.

Variation in the average tree class of 100 trees was less than one percent as additional groups of 100 randomly selected trees were classified. The first group of 100 trees had an average production class of 2.25. When the second 100 trees were added to this for a sample of 200 trees, the average class was 2.27 and remained the same with the addition of another 100 trees.

There was a significant (t test with P=.05) difference based on both sample weight and number of acorns per sample between Class 2, 3 and 4 trees (table 1). No acorns were collected from Class 1 trees. The number of acorns collected per trap correlated positively (r=0.59, P=.05) with the visual class. There was no significant difference in the range of the DBH (Diameter Breast High-a measurement of basal area) for trees

Table 1--Acorn trap summary data per tree class

	Class 2(16)[1]	Class 3(46)	Class 4(36)
Mean acorns/trap ± Standard error (Range)	1.2± .76 (0.44-1.96)	5.0± 2.15 (2.86-7.14)	19.0± 5.7 (13.23-24.76)
Mean wt. gm /trap (Range)	1.2± .83 (0.37-2.03)	10.6± 4.13 (6.47-14.70)	42.4± 11.02 (31.60-53.20)

[1] Number of trees sampled.

Table 2--Average acorn yield class by species, county, and region, 1978

County	All Species	Blue Oak	Black Oak	Brewer Oak	Canyon L. Oak	Coast L.Oak	Garry Oak	Interior L. Oak	Scrub Oak	Valley Oak
Tehama		1.35(328)[1]								
TOTAL	1.35(328)	1.35(328)								
El Dorado	1.82(355)		1.71(300)		2.41(55)					
Glenn-Colusa	1.02(300)	1.00(100)	1.05(100)	1.00(*)	1.10(*)[2]			1.05(*)		1.00(100)
TOTAL	1.45(655)	1.00(100)	1.55(400)	1.00(*55)				1.05(*)		1.00(100)
Napa	1.32(1116)	1.07(217)	1.67(82)				1.00(500)	1.89(317)		
Mendocino	1.42(217)		1.65(77)				1.34(98)	1.21(42)		
Lake	1.65(2956)	1.22(490)	1.61(1097)	1.92(137)	1.71(45)		1.13(401)	2.19(528)		2.12(258)
San Luis Obispo										
Monterey	1.43(500)	1.16(200)				1.13(100)		2.54(100)		1.16(100)
Santa Clara	1.03(1200)	1.00(300)	1.04(200)					1.04(400)		1.03(300)
Sonoma	2.12(381)		1.85(82)				1.37(83)	2.52(216)		
TOTAL	1.33(6370)	1.13(1207)	1.55(1538)	1.92(137)	1.71(45)	1.13(100)	1.11(1082)	1.88(1603)		1.48(658)
Stanislaus	1.03(240)	1.03(240)								
Madera	1.00(100)	1.00(100)								
TOTAL	1.02(340)	1.02(340)								
COMBINED TOTALS										
1978	1.45(7695)	1.14(1975)	1.55(1940)	1.92(137)	2.09(100)	1.13(100)	1.11(1082)	1.88(1603)		1.42(758)
1977	1.70(7388)	1.72(1811)	1.68(2588)	1.83(227)	1.85(432)	1.86(200)	1.50(699)	1.66(584)	1.23(70)	1.74(772)
1976	2.05(3067)	1.80(678)	1.84(960)	2.92(100)	2.89(211)	2.30(100)	2.00(220)	2.09(480)	1.29(7)	2.32(311)

[1] Number in parentheses indicates sample size.

[2] Sample size unknown.

in each visual class, with ranges of 32-132 for Class 2, 98-162 for Class 3, and 124-236 for Class 4 trees.

Application of the visual method to monitor acorn yields on a statewide basis shows an observed decline in mast production for most species and administrative regions (tables 2 and 3). Sampling intensity varied between observers, and only limited data was available for some species. Therefore, no statistical analysis of the data was attempted.

Table 3--Combined average yield classes of all oak species by county and region for 1976, 1977, and 1978

COUNTY	1976	1977	1978
Siskiyou	2.47(100)	1.85(300)	
Humboldt		1.87(116)	
Trinity	1.46(155)	1.45(165)	
Tehama	1.81(476)	2.27(350)	1.35(328)
REGION 1	1.83(731)	1.94(931)	1.35(328)
El Dorado	1.44(300)	1.33(352)	1.82(355)
Placer	1.74(100)	1.78(400)	
Glenn-Colusa	2.43(700)	1.50(600)	1.02(300)
REGION 2	2.10(1100)	1.54(1352)	1.45(655)
Mendocino	2.37(300)	1.83(185)	1.42(217)
Lake	2.32(76)	1.59(2815)	1.65(2956)
San Luis Obispo		2.39(500)	
Monterey	1.80(100)	1.78(500)	1.43(500)
Santa Clara	1.66(160)	1.42(345)	1.03(1200)
Napa			1.32(1116)
Sonoma			2.12(381)
REGION 3	2.10(636)	1.70(4345)	1.33(6370)
Stanislaus	1.48(100)	1.42(260)	1.03(240)
Madera	2.56(100)	1.37(100)	1.00(100)
REGION 4	2.02(200)	1.41(360)	1.02(340)
San Bernardino		1.64(200)	
San Diego	2.60(200)	2.41(200)	
Riverside	1.93(200)		
REGION 5	2.26(400)	2.02(400)	*

* = Sample size unknown.
Number in parentheses indicates sample size.

DISCUSSION AND RECOMMENDATIONS

The visual classification method for estimating acorn production for a given tree or area is easily adapted to many oak management or research needs. With very little direction or training, several observers can classify acorn production in a given geographical area or in several areas using a uniform classification system. The method works well on all mast-producing species that were sampled. The untrained observers found the method easy to follow and applicable to their areas and various species of oaks. The significant correlation between the visual class and measured acorn production suggests that the visual classification system could be used to quantify annual acorn production, providing some information including basal area, stems per acre, average canopy height, and crown cover per acre on the tree stand and area is available. We intend to collect quantitative data and visually classify trees on our blue oak study area through at least one more good acorn year in order to correlate the visual classification to quantitative mast production. We also intend to follow the same procedure with black oak (Q. Kelloggii) during a good mast year. Questions asked are: What constitutes an average or above average mast crop? Are the same trees that produce one good year the same ones that produce during the next good year? These questions can be answered only after several years of data are available.

Assuming that the strong correlation exists between visual class and quantitative measurement of mast production for all oak species, the visual method can be used as a research and management tool. The researcher can use it to measure mast production in conjunction with food habits, body condition, reproductive levels, and population trends of selected wildlife species. The visual classification can be used to sample a larger number of trees over a much larger area than the more expensive and time-consuming conventional seed trap method. Provided that trees are classified and marked during good mast years, the land manager can use the method as a tool for selecting good mast-producing trees of various sizes and age classes to be retained during logging and thinning operations for the benefit of wildlife and for natural reseeding of the area.

The Department of Fish and Game will continue to use this method to monitor acorn production throughout the state. The annual data and trend information will be used in conjunction with deer, bear, and pigeon research. It will be used to forecast trends in squirrel populations and pigeon concentrations. As more data become available through our research, we intend to incorporate the visual classification method into oak management plans for public and private lands as a tool for selecting good mast-producing trees to be left during thinning and logging operations.

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Quercus kelloggii

Mammals of California Oak Habitats—Management Implications[1]

Reginald H. Barrett[2]

Abstract: A review of published literature on 169 terrestrial mammal species and 15 species of oaks in California established that at least 60 mammals may use oaks in some way. Thirty-eight mammals cannot or do not utilize oaks and 71 species need further study. It is proposed that ongoing land management practices affecting oaks be monitored to determine the effect of such practices on mammal populations. There are no published studies clearly documenting the effect on a mammal population of removing oaks from a site in California.

INTRODUCTION

Approximately 20 million acres or 20 percent of California is vegetated with some combination of 6 species of oaks and related mast producing trees and shrubs. It is not surprising then that a major proportion of the state's mammalian fauna utilizes oaks for food and cover.

A number of vegetation or habitat classification schemes has been devised for the state (Jensen 1947, Munz and Keck 1959, Cheatham and Haller 1975, Kuchler 1977, Barbour and Major 1977), and one can find lists of mammals that may be associated with most of these habitat types (Grinnell and Storer 1924, Grinnell and Linsdale 1930, Grinnell 1933, Grinnell et al. 1937, Hamilton 1939, Sumner and Dixon 1953, Brown 1957, Ingles 1965). Rather than repeat such lists here, I will review the relationships of oaks and mammals in California by extracting from the published literature on both oaks and mammals of the state information on: 1) the overlap in the ranges of 15 oak species and 169 terrestrial mammal species; and 2) the type and degree of utilization of oaks by these mammals. An important result of this exercise has been the realization that for most of these 169 mammals we do not know whether they utilize a given oak species, much less if they are strongly dependent on any of them.

RANGE OVERLAP

On the assumption that to interact two organisms must have overlapping distributions, I compared the ranges of 15 oaks (including tan oak[3] (Sampson and Jesperson 1963, Griffin and Critchfield 1972) with those of 169 terrestrial mammals including 11 introduced species (Ingles 1965, Burt and Grossenheider 1976). Of the 2,535 potential interactions (Appendix I), 56 percent could be considered as cases in which a mammal species might interact with an oak (table 1). Forty-four percent were cases in which the respective ranges did not overlap, consequently interactions are impossible. However, only 3 percent of all cases, or 5 percent of the cases with some overlap, could be documented from the literature as ones in which the mammal species actually utilized the specific oak for food or cover. Thus 53 percent of all cases need further study. Some additional information may exist but not in published form readily available to land managers.

For many mammals the literature indicated use of oak in general, or documentation was available for use of oaks outside of California (Van Dersal 1940, Martin et al. 1951, Ingles 1965). Considering this information as well as that above, 60 mammals or 35 percent of the 169 total may use oaks directly or indirectly (table 2). This group includes the 21 mammals listed by Barrett et al. (1976). Thirty-eight mammals cannot or do not utilize oaks and 71 species need further study according to this analysis.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, Calif., June 26-28, 1979.

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[3] Scientific names of oak species are given in Appendix 1.

Types of Utilization

Oaks provide thermal or escape cover for at least 55 California mammals (Ingles 1965, Barrett et al. 1976, Verner and Boss, in press). For example, grey fox[4/] and bobcat may use dense oak chaparral as thermal cover (Grinnell et al. 1937).

Table 1--*Interactions and potential interactions between 169 terrestrial California mammal species and 15 California oak species, including tan oak*

	NUMBER OF CASES	PERCENT
POTENTIAL INTERACTIONS (15 x 169)	2,535	100
DOCUMENTED STRONG DEPENDENCE OF 5 MAMMALS ON OAK SPECIES FOR COVER OR FOOD	16	1
DOCUMENTED UTILIZATION OF OAK SPECIES BY 55 MAMMALS FOR COVER OR FOOD (EXCLUDING CASES OF STRONG DEPENDENCE)	51	2
DOCUMENTED INTERACTION	67	3
OVERLAP OF MAMMAL AND OAK SPECIES RANGES BUT NO DOCUMENTED USE OR OTHER INTERACTIONS (CASES IN NEED OF FURTHER STUDY)	1,168	46
MINIMAL OVERLAP OF MAMMAL AND OAK SPECIES RANGES	195	7
NO PUBLISHED DATA	1,363	53
NO OVERLAP OF MAMMALS' RANGE WITH OAK SPECIES' RANGE (EXCLUDING CASES BELOW)	925	37
NO OVERLAP OF 12 MAMMALS' RANGES WITH ANY OF 15 OAK SPECIES	180	7
NO INTERACTION	1,105	44

Raccoons may use hollow oaks as den sites or escape cover (Grinnell et al 1937). Black bears may den under the roots of large oaks (Piekielek and Burton 1975). Fallen oaks make good cover for deer mice and striped skunks (Ingles 1965). Of course, in most of these cases the mammal is not restricted to oaks and could substitute similar vegetation. In this sense these species are not dependent on oaks per se. However, in many cases where oaks are being altered or eliminated, no satisfactory substitutes are available. Gray squirrels and fox squirrels are probably the California mammals most dependent on oaks for cover, but even they may use trees other than oaks for den sites.

Oaks provide considerable browse for many small and large mammals despite the fact that most oaks have substantial amounts of tannins or essential oils in their leaves (Mackie 1903, Van Dersal 1940). Voles, pocket gophers, and deer all forage on the leaves and twigs of many oak species, especially young seedlings (Martin et al. 1951, Griffin 1971). Even dry leaves of the deciduous oaks may provide food for deer (Leach and Hiehle 1957). As Griffin has illustrated elsewhere in this symposium, the foraging of mammals may be a significant factor inhibiting growth and even survival of oaks, particularly in the case of young trees (Mellanby 1968, Griffin 1971). The browsing domestic livestock and deer may be the most significant factor inhibiting the regeneration of oaks on California rangelands (Longhurst et al. 1979).

Clearly the greatest importance of oaks to mammals lies in their production of large, edible seeds (Martin et al. 1951, Christensen and Korschgen 1955, Reid and Goodrum 1957). Acorns have a high caloric density (Ofcarcik and Burns 1971, Barrett et al. 1976), and since they are relatively large, it is worthwhile for many mammals to expend considerable energy foraging for them. At least 37 (22 percent) of California's terrestrial mammals are known to utilize acorns. No species may be absolutely dependent on acorns if alternate foods are available, but several species--especially bears, deer, pigs and squirrels--could not maintain normal densities without a fairly regular supply of acorns (Piekielek and Burton 1975, Dasmann 1971, Goodrum 1940, Barrett 1978).

Table 2 --*Utilization of oak by 169 terrestrial California mammals*

	NO. SPECIES	PERCENT
DOCUMENTED USE OF OAK FOR FOOD OR COVER, DIRECTLY OR INDIRECTLY	60	35
USE OF OAK FOR COVER	55	33
USE OF OAK FOR FOOD	24	14
USE OF OAK FOR BOTH FOOD AND COVER	23	14
POSSIBLE BUT UNDOCUMENTED USE OF OAK	71	43
NO APPARENT USE OF OAK	26	15
NO POSSIBLE USE OF OAK	12	7
TOTAL	169	100

[4/] Scientific names of mammal species are given in Appendix 1.

Over much of their range these mammals tend to fluctuate in density according to the annual crop of mast, indicating they are limited by this source of food (Allen 1943, Burns et al. 1954, Uhlig 1956, Duvendeck 1962, Matschke 1964, Barrett 1978).

The utilization rate of mast crops by mammals has rarely been measured, but my own observations throughout California suggest that acorns other than those of tan oak rapidly disappear once they have dropped. Acorn utilization usually approaches 100 percent where deer, pigs or bear occur. Consequently, the density, age structure, dispersion pattern, and species composition of oaks within the home range of a mammal strongly dependent on acorns will undoubtedly influence the density and productivity of that species.

With this in mind, wildlife biologists have provided the following recommendation for maintaining oak dependent wildlife:

1) maintain a 25 to 50 percent canopy cover in oaks,
2) maintain a basal area of 200 to 2000 ft^2 per each 40 acres,
3) maintain a mixture of age classes including older, more prolific seeders,
4) disperse oaks in 0.5- to 5-acre aggregations.

A mixture of deciduous and evergreen oaks is preferable because this tends to provide a more even production of mast (Reynolds et al. 1970, Goodrum et al. 1971, Connell et al. 1973). From the viewpoint of oak regeneration, however, a pulsed seed crop is desirable. The widespread occurrence of irregular seed production is presumably a result of long coevolution of both oaks and their seed predators (Sudworth 1908, USFS 1948, Harper 1977). Squirrels, like jays, not only eat acorns but disperse them, thus playing a double role in the ecology of oaks.

Oaks may be important to some mammals by supporting oak dependent fungi, lichens, mistletoe, galls or insect species required or preferred by these mammals (Van dersal 1940, Ingles 1965). There is much more to be learned about such relationships. Another indirect relationship is that between the larger mammalian carnivores and oaks. Although carnivores in general are relatively catholic in their food preferences, some species such as the mountain lion prefer deer which may be dependent on oaks. Thus a productive oak woodland or shrubland should support not only a dense deer herd but a healthy lion population as well. A comparison of mountain lion distribution in California (Koford 1977) with that of oaks (Griffin and Critchfield 1972) suggests this relationship.

In the analysis of oak-mammal interactions I also considered which oak species seemed to be utilized most commonly by California mammals (Appendix I). The top 6 oak species included valley oak, interior live oak, California black oak, canyon oak, coast live oak and blue oak (table 3). Of these, apparently the most likely to be reduced by human activities are valley oak, black oak and blue oak. The human activities concerned are agricultural crop production, timber production, and livestock production respectively.

Table 3. *Importance of oak species to California mammals based on the number of documented interactions between each oak and 169 mammals.*

OAK SPECIES	NO. CASES	PERCENT
VALLEY OAK	14	21
INTERIOR LIVE OAK	13	19
CALIFORNIA BLACK OAK	7	11
CANYON OAK	6	9
COAST LIVE OAK	6	9
BLUE OAK	5	7
SCRUB OAK	4	6
OREGON OAK	3	4
LEATHER OAK	3	4
HUCKLEBERRY OAK	3	4
ENGELMAN OAK	1	2
DEER OAK (SADLER OAK)	1	2
TAN OAK	1	2
TURBIN OAK (SHRUB LIVE OAK)	0	0
PALMER OAK (DUNN OAK)	0	0
TOTAL	67	100

MANAGEMENT IMPLICATIONS

Several California mammals are strongly dependent on oaks, many others utilize oaks to some degree, and even more species simply are not known well enough to make conclusions about their relationships with oaks. Several important oak species, while still common now, may be significantly reduced in numbers in the foreseeable future due to human activities and to influences of domestic and wild mammals. Therefore, land managers should reconsider their objectives in light of societies' future needs and modify their programs accordingly. If it is determined that a reasonable population of each native California mammal should be maintained in most portions of their pristine ranges, land managers must

1) determine cause and effect relationships between oaks and mammals (not to mention wildlife in general), and
2) develop management programs to interface societies' needs for crops, timber and livestock production with needs for wildlife conservation.

I suggest that the primary need at this time is to document the requirements of California wildlife for oaks. The most practical and efficient way to do this is to monitor present oak manipulation practices as well as the proposed practices outlined above. Such a program of monitoring wildlife responses should be considered part of management costs (Leopold 1978). Monitoring must be carried out with proper consideration for experimental design, adequate sample size and appropriate criteria for measurements. I suggest the relative abundance of each mammal species should be considered as a minimum.

I am not aware of any published studies that have adequately determined cause and effect relationships between oaks and mammals in California. The present is the time to begin a series of monitoring studies if there is to be any time to modify existing management procedures before many alternatives are foreclosed. In the meantime, managers must be satisfied with a hodgepodge of subjective recommendations based on generally unsubstantiated claims.

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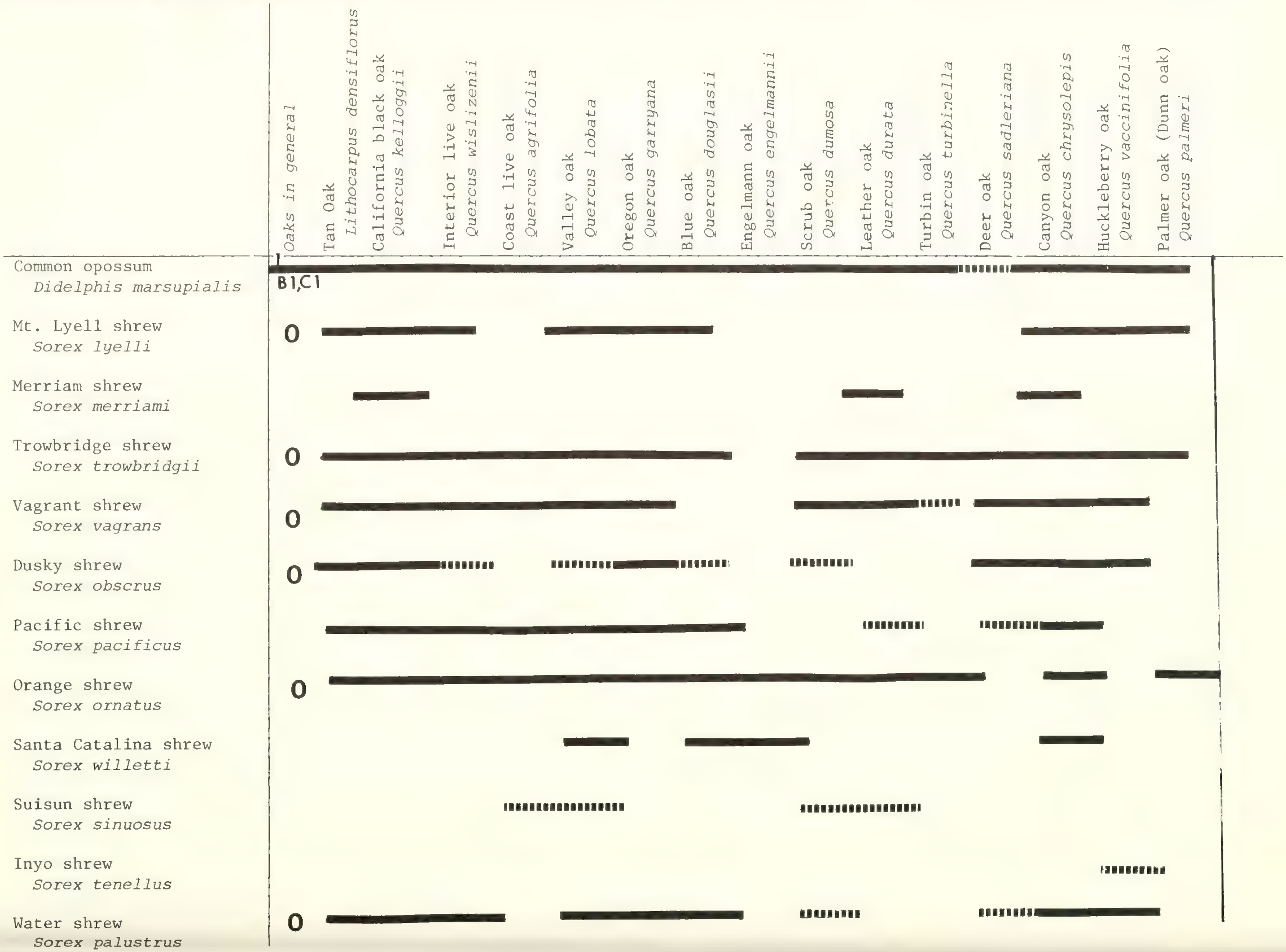
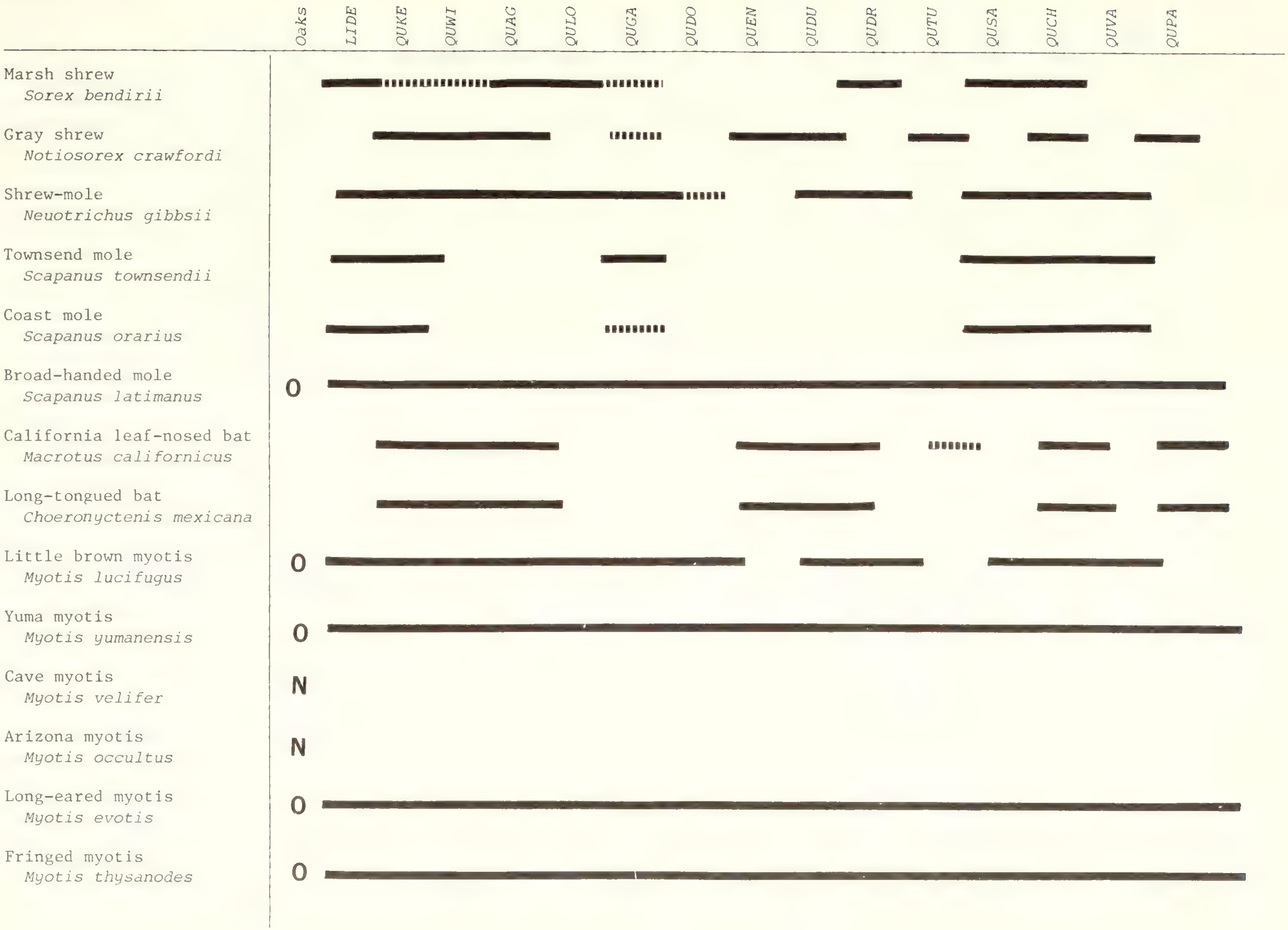
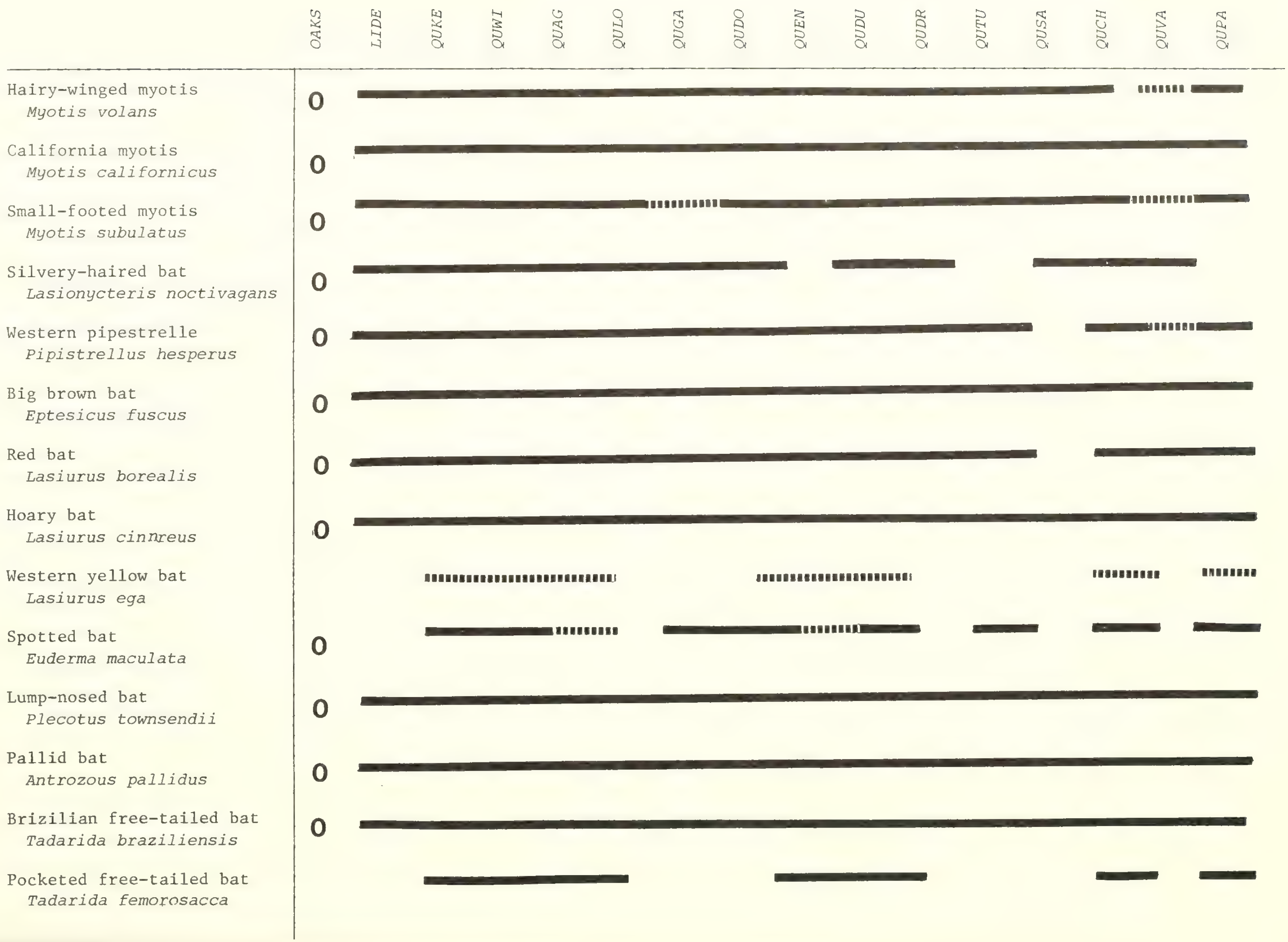
Appendix I--*Matrix of potential and documented interactions between 169 terrestrial mammals and 15 oaks in California. Documentation was derived from sources reviewed by VanDersal (1940), Martin et al. (1951), Ingles (1965),Barrett et al (1976) and Verner and Boss (in press).*




Oaks
LIDE
QUKE
QUWI
QUAG
QULO
QUGA
QUDO
QUEN
QUDU
QUDR
QUTU
QUSA
QUCH
QUVA
QUPA
Marsh shrew
Sorex bendirii
Gray shrew
Notiosorex crawfordi
Shrew-mole
Neuotrichus gibbsii
Townsend mole
Scapanus townsendii
Coast mole
Scapanus orarius
Broad-handed mole
Scapanus latimanus
O
California leaf-nosed bat
Macrotus californicus
Long-tongued bat
Choeronyctenis mexicana
Little brown myotis
Myotis lucifugus
O
Yuma myotis
Myotis yumanensis
O
Cave myotis
Myotis velifer
N
Arizona myotis
Myotis occultus
N
Long-eared myotis
Myotis evotis
O
Fringed myotis
Myotis thysanodes
O


OAKS
LIDE
QUKE
QUWI
QUAG
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QUGA
QUDO
QUEN
QUDU
QUDR
QUTU
QUSA
QUCH
QUVA
QUPA
Hairy-winged myotis
Myotis volans
California myotis
Myotis californicus
Small-footed myotis
Myotis subulatus
Silvery-haired bat
Lasionycteris noctivagans
Western pipestrelle
Pipistrellus hesperus
Big brown bat
Eptesicus fuscus
Red bat
Lasiurus borealis
Hoary bat
Lasiurus cinnreus
Western yellow bat
Lasiurus ega
Spotted bat
Euderma maculata
Lump-nosed bat
Plecotus townsendii
Pallid bat
Antrozous pallidus
Brizilian free-tailed bat
Tadarida braziliensis
Pocketed free-tailed bat
Tadarida femorosacca
0
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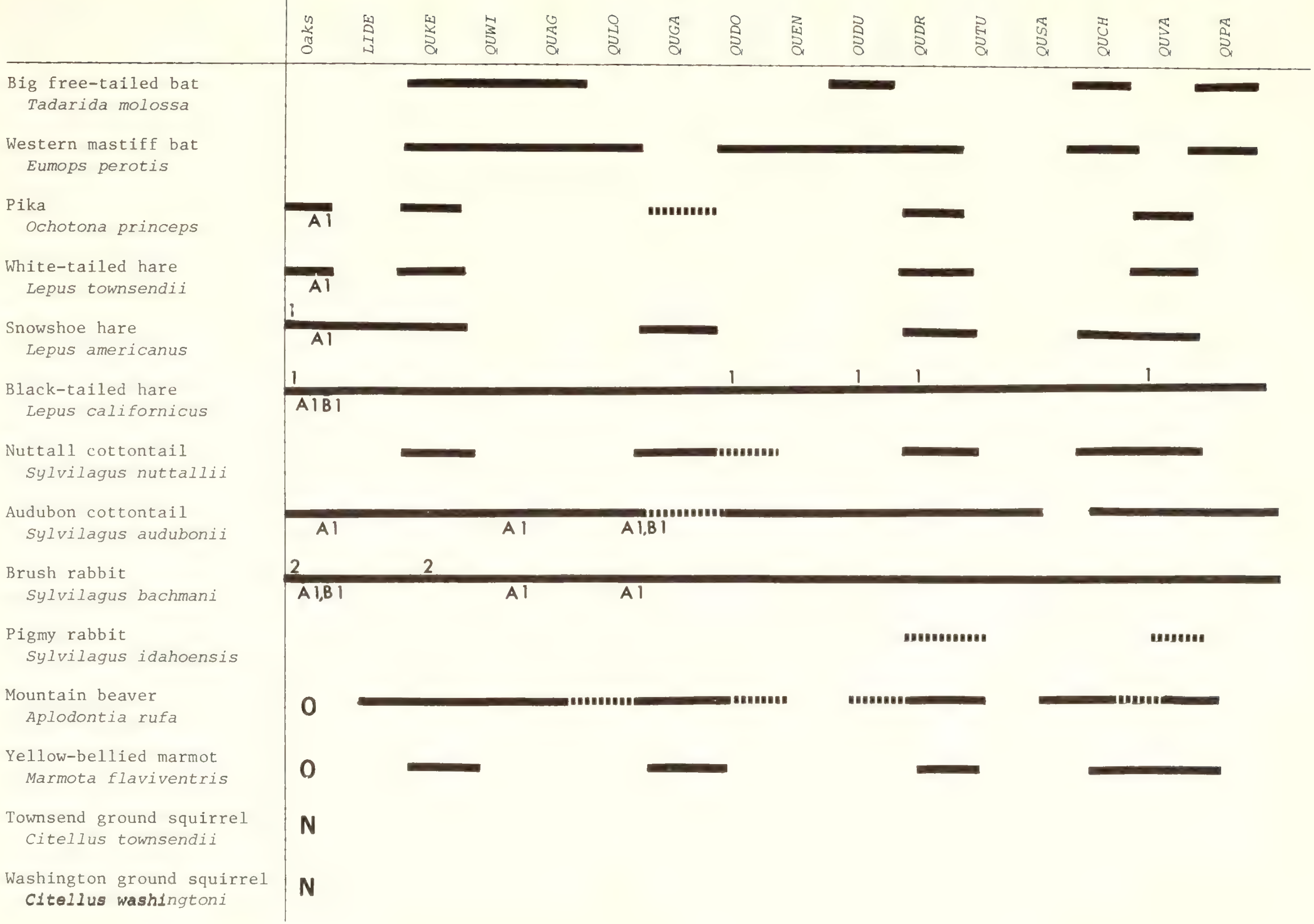
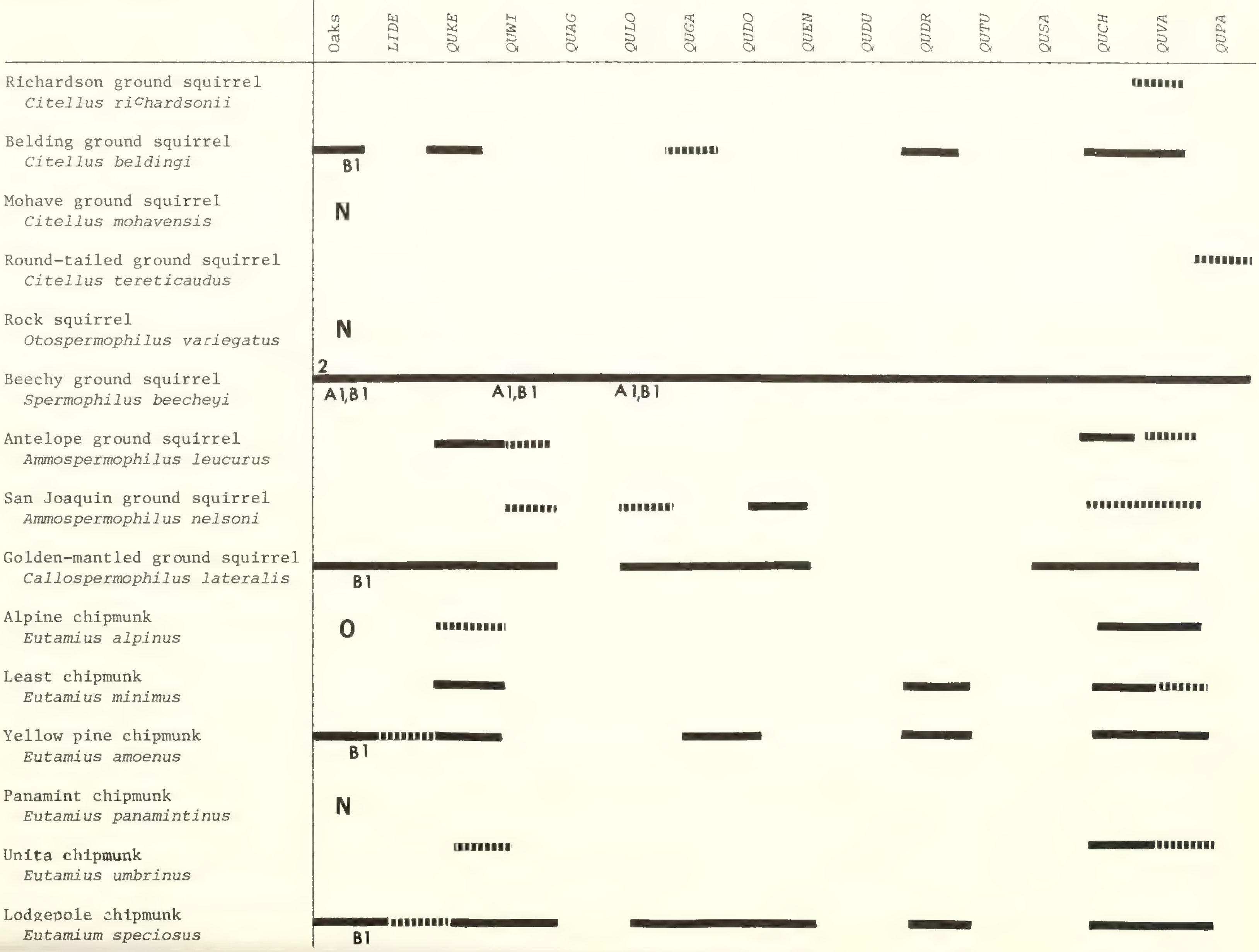
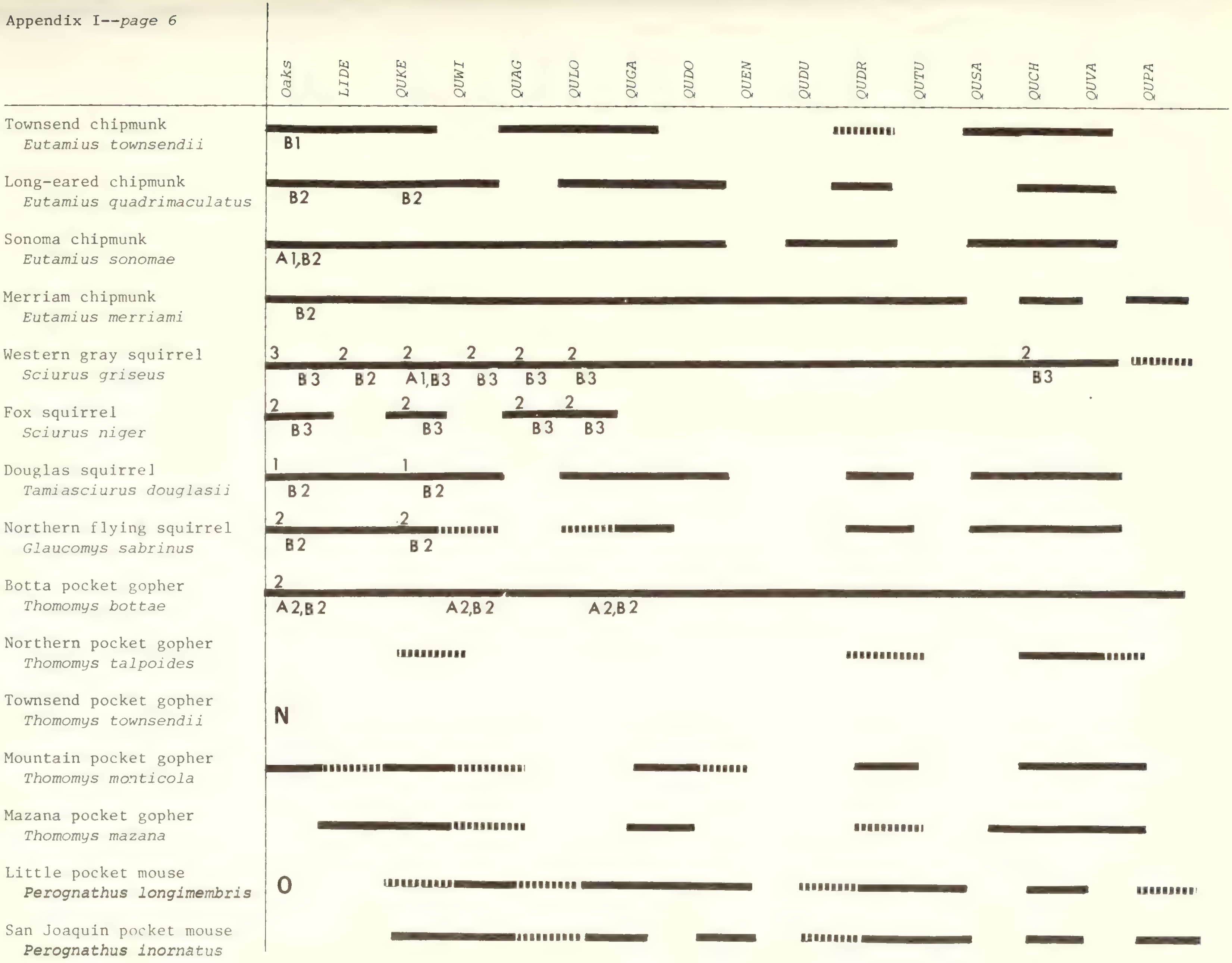
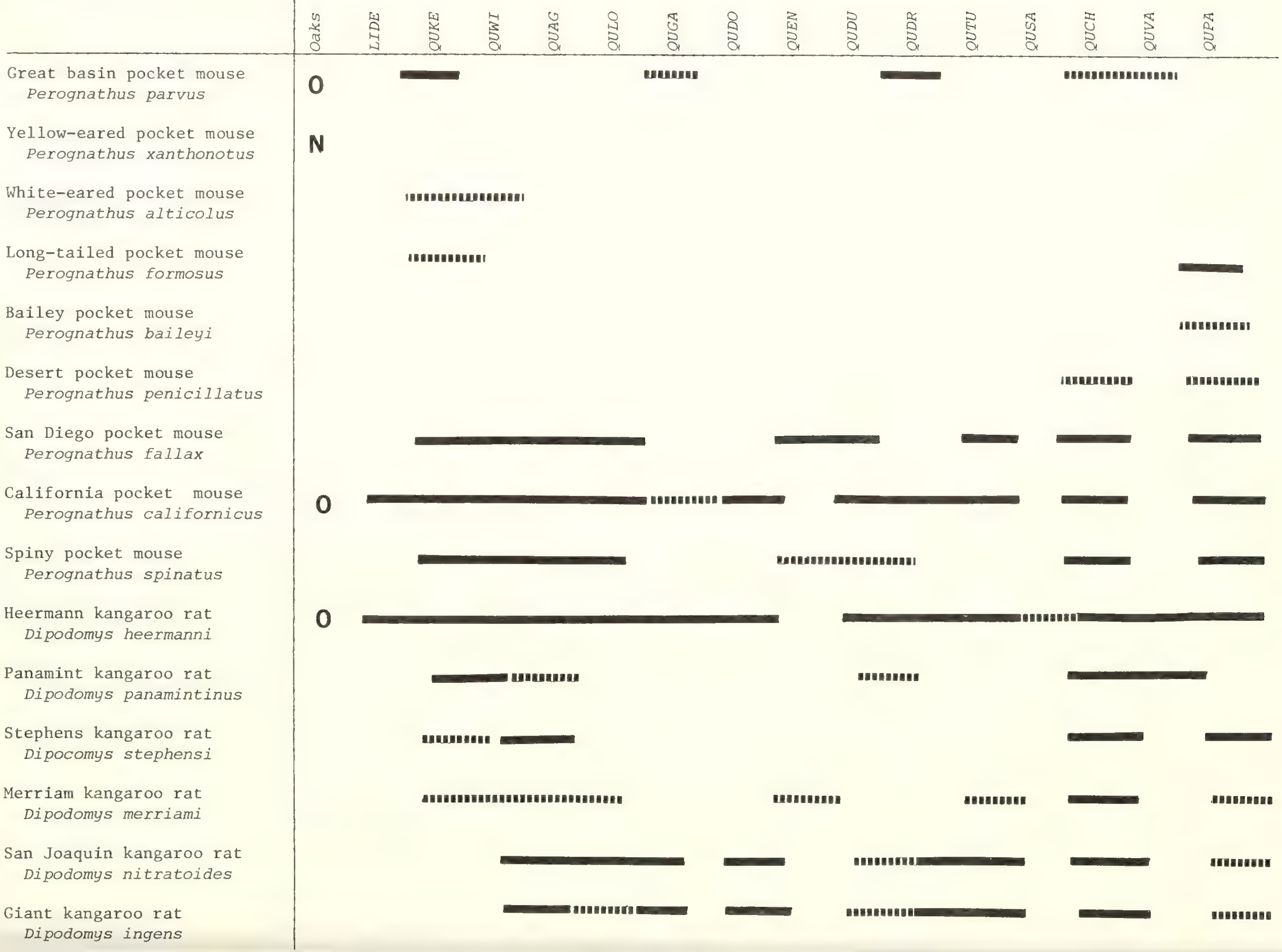
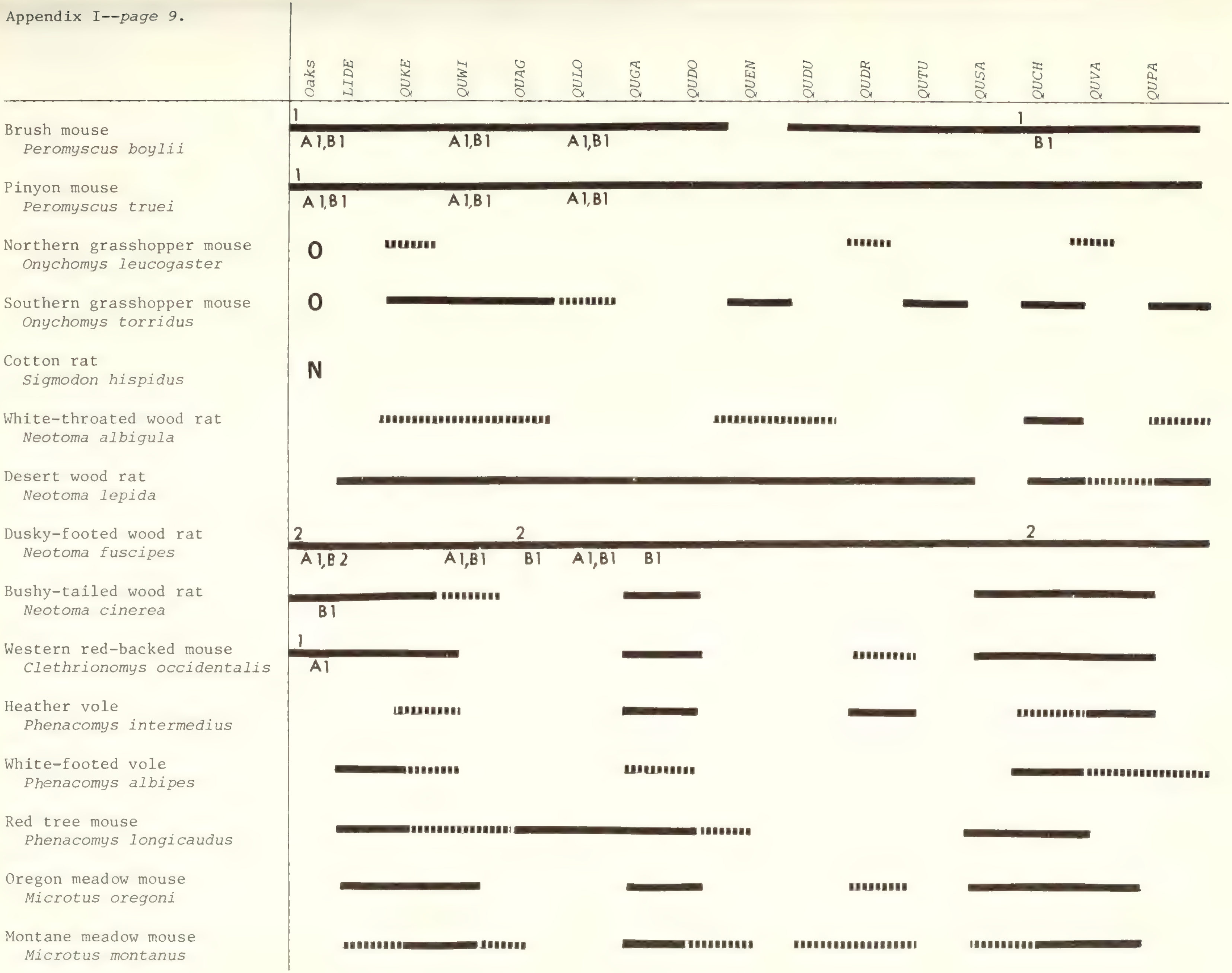

Oaks
LIDE
QUKE
QUWI
QUAG
QULO
QUGA
QUDO
QUEN
OUDU
QUDR
QUTU
QUSA
QUCH
QUVA
QUPA
Big free-tailed bat
Tadarida molossa
Western mastiff bat
Eumops perotis
Pika
Ochotona princeps
A1
White-tailed hare
Lepus townsendii
A1
Snowshoe hare
Lepus americanus
1
A1
Black-tailed hare
Lepus californicus
1
1
1
1
1
A1B1
Nuttall cottontail
Sylvilagus nuttallii
Audubon cottontail
Sylvilagus audubonii
A1
A1
A1,B1
Brush rabbit
Sylvilagus bachmani
2
2
A1,B1
A1
A1
Pigmy rabbit
Sylvilagus idahoensis
Mountain beaver
Aplodontia rufa
O
Yellow-bellied marmot
Marmota flaviventris
O
Townsend ground squirrel
Citellus townsendii
N
Washington ground squirrel
Citellus washingtoni
N


Oaks
LIDE
QUKE
QUWI
QUAG
QULO
QUGA
QUDO
QUEN
QUDU
QUDR
QUTU
QUSA
QUCH
QUVA
QUPA
Richardson ground squirrel
Citellus richardsonii
Belding ground squirrel
Citellus beldingi
B1
Mohave ground squirrel
Citellus mohavensis
N
Round-tailed ground squirrel
Citellus tereticaudus
Rock squirrel
Otospermophilus variegatus
N
2
Beechy ground squirrel
Spermophilus beecheyi
A1,B1
A1,B1
A1,B1
Antelope ground squirrel
Ammospermophilus leucurus
San Joaquin ground squirrel
Ammospermophilus nelsoni
Golden-mantled ground squirrel
Callospermophilus lateralis
B1
Alpine chipmunk
Eutamius alpinus
O
Least chipmunk
Eutamius minimus
Yellow pine chipmunk
Eutamius amoenus
B1
Panamint chipmunk
Eutamius panamintinus
N
Unita chipmunk
Eutamius umbrinus
Lodgepole chipmunk
Eutamium speciosus
B1

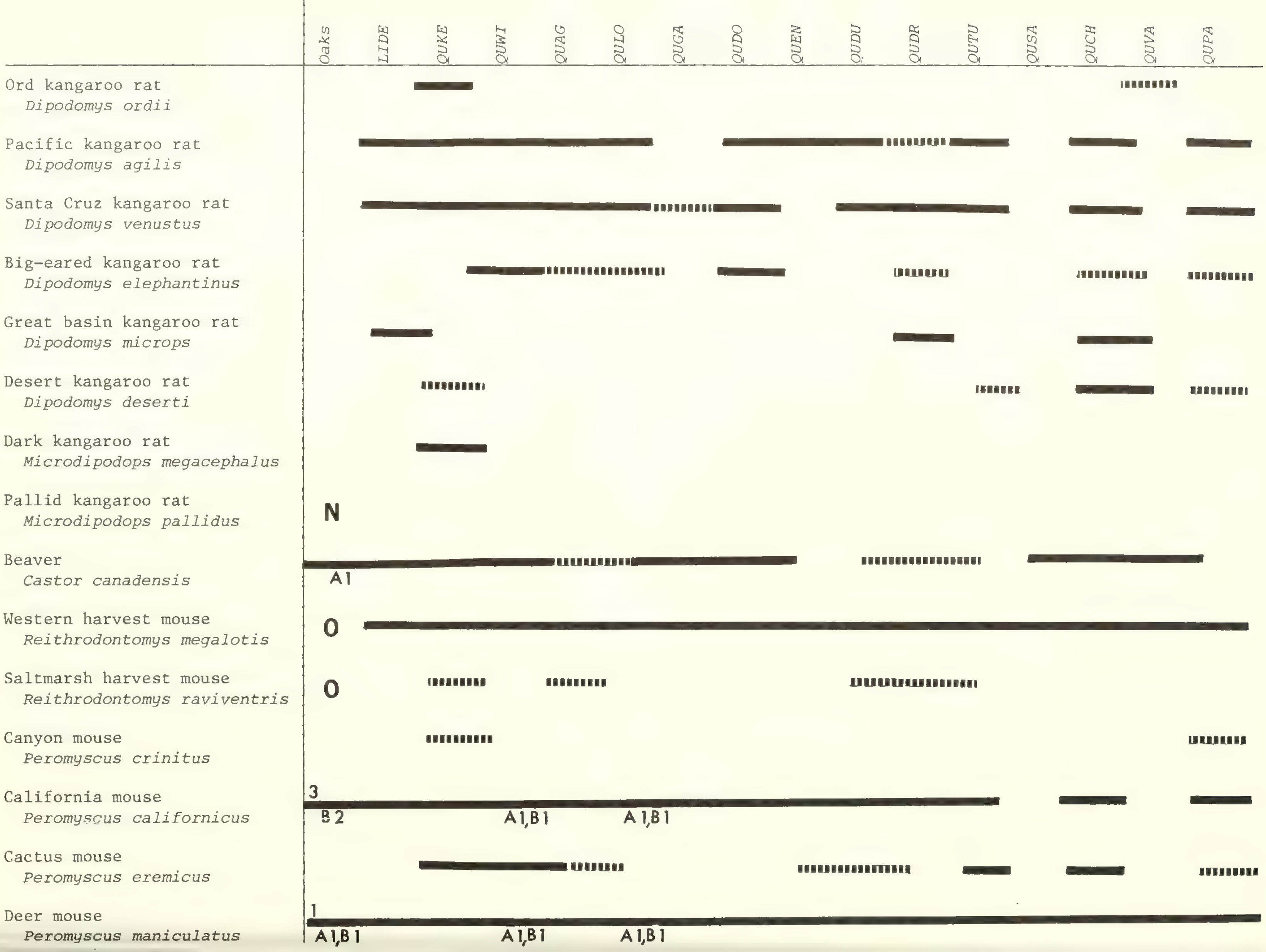

Oaks
LIDE
QUKE
QUWI
QUAG
QULO
QUGA
QUDO
QUEN
QUDU
QUDR
QUTU
QUSA
QUCH
QUVA
QUPA
Townsend chipmunk
Eutamius townsendii
B1
Long-eared chipmunk
Eutamius quadrimaculatus
B2
B2
Sonoma chipmunk
Eutamius sonomae
A1,B2
Merriam chipmunk
Eutamius merriami
B2
Western gray squirrel
Sciurus griseus
3
2
2
2
2
2
2
B3
B2
A1,B3
B3
B3
B3
B3
Fox squirrel
Sciurus niger
2
2
2
2
B3
B3
B3
B3
Douglas squirrel
Tamiasciurus douglasii
1
1
B2
B2
Northern flying squirrel
Glaucomys sabrinus
2
2
B2
B2
Botta pocket gopher
Thomomys bottae
2
A2,B2
A2,B2
A2,B2
Northern pocket gopher
Thomomys talpoides
Townsend pocket gopher
Thomomys townsendii
N
Mountain pocket gopher
Thomomys monticola
Mazana pocket gopher
Thomomys mazana
Little pocket mouse
Perognathus longimembris
O
San Joaquin pocket mouse
Perognathus inornatus

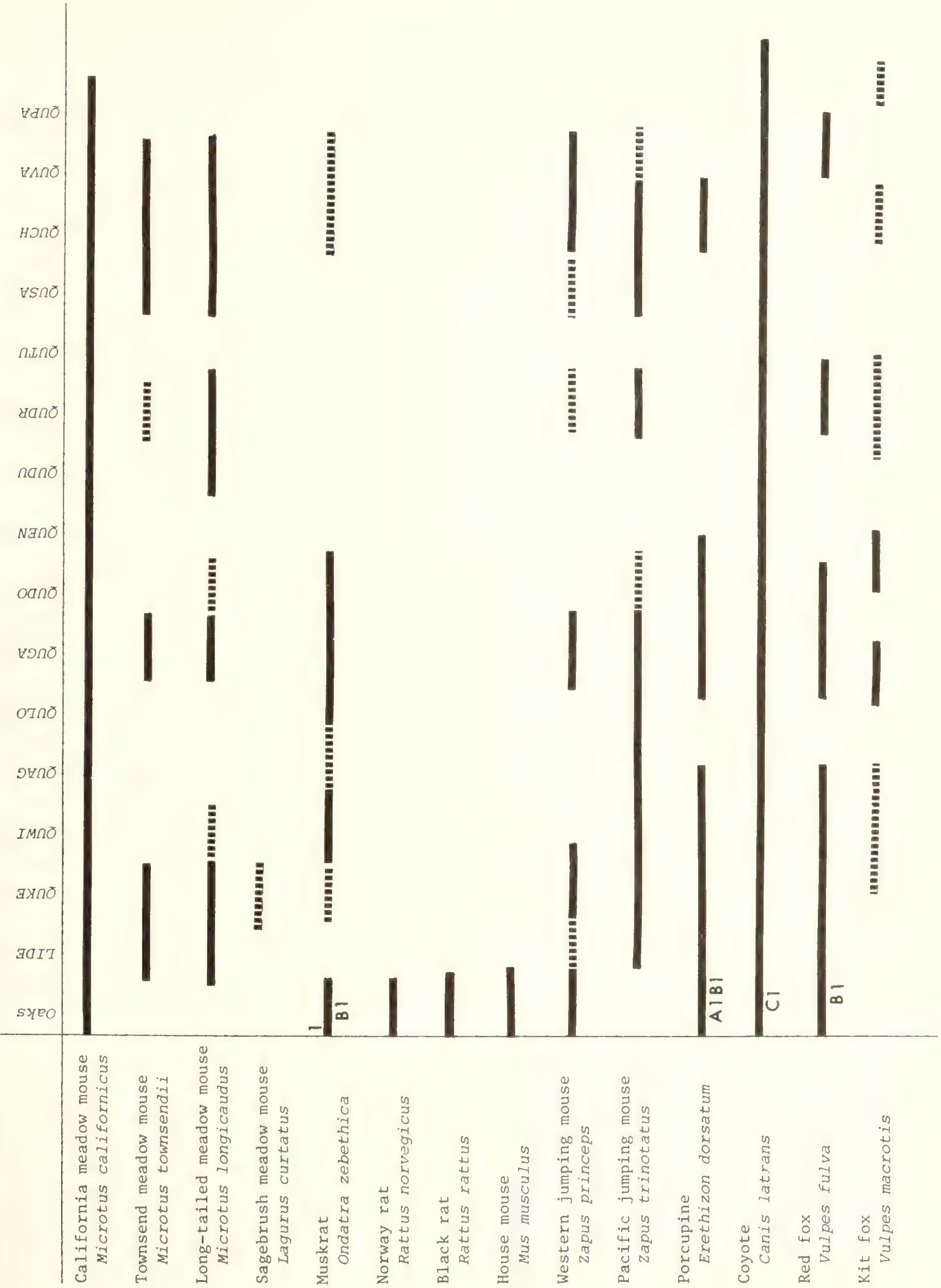
Appendix I--*page 7*



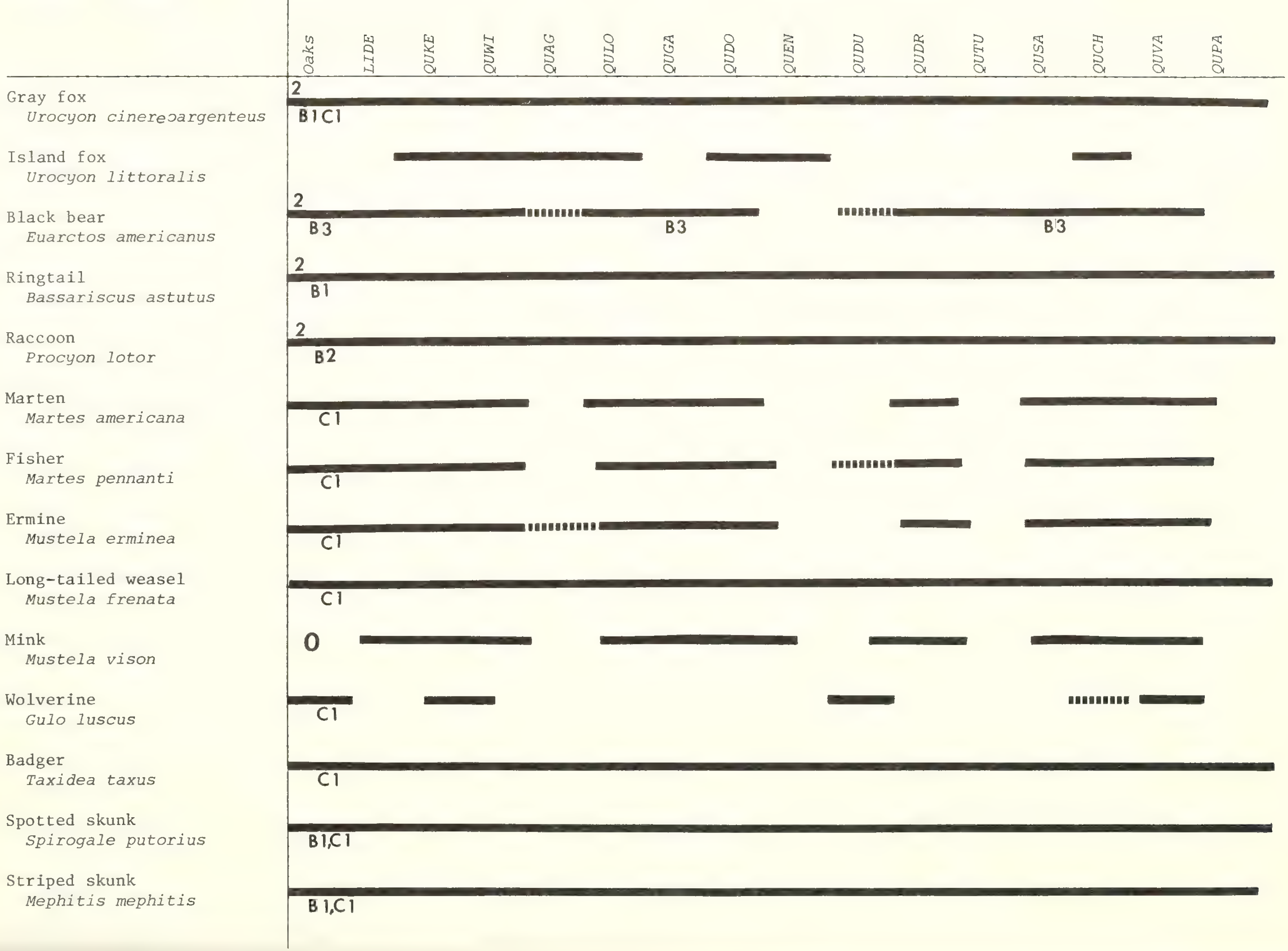

Oaks
LIDE
QUKE
QUWI
QUAG
QULO
QUGA
QUDO
QUEN
QUDU
QUDR
QUTU
QUSA
QUCH
QUVA
QUPA
Brush mouse
Peromyscus boylii
1
A1,B1
A1,B1
A1,B1
1
B1
Pinyon mouse
Peromyscus truei
1
A1,B1
A1,B1
A1,B1
Northern grasshopper mouse
Onychomys leucogaster
O
Southern grasshopper mouse
Onychomys torridus
O
Cotton rat
Sigmodon hispidus
N
White-throated wood rat
Neotoma albigula
Desert wood rat
Neotoma lepida
Dusky-footed wood rat
Neotoma fuscipes
2
2
2
A1,B2
A1,B1
B1
A1,B1
B1
Bushy-tailed wood rat
Neotoma cinerea
B1
Western red-backed mouse
Clethrionomys occidentalis
1
A1
Heather vole
Phenacomys intermedius
White-footed vole
Phenacomys albipes
Red tree mouse
Phenacomys longicaudus
Oregon meadow mouse
Microtus oregoni
Montane meadow mouse
Microtus montanus

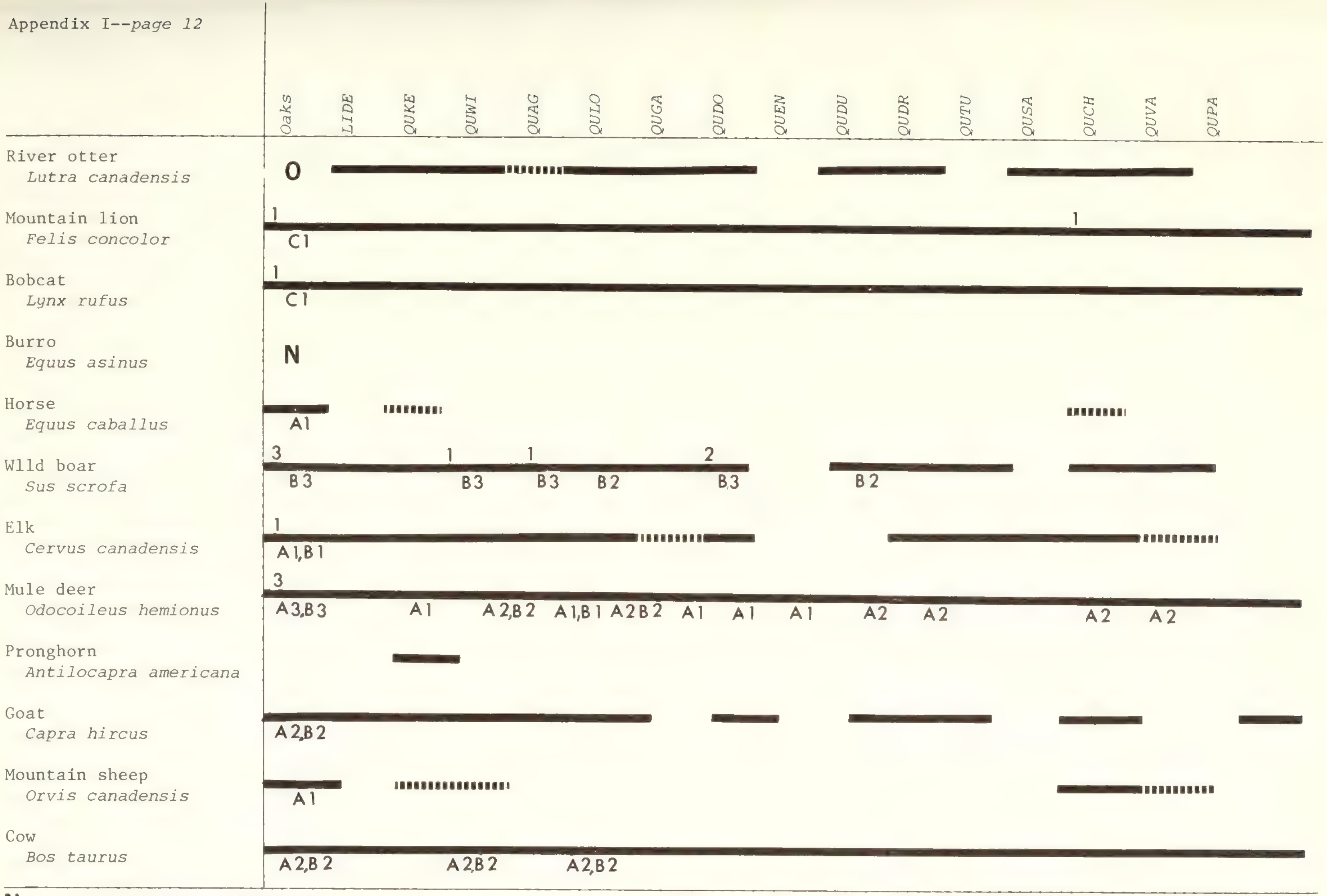
Appendix I--*page 8*




Oaks
LIDE
QUKE
QUWI
QUAG
QULO
QUGA
QUDO
QUEN
QUDU
QUDR
QUTU
QUSA
QUCH
QUVA
QUPA
California meadow mouse *Microtus californicus*
Townsend meadow mouse *Microtus townsendii*
Long-tailed meadow mouse *Microtus longicaudus*
Sagebrush meadow mouse *Lagurus curtatus*
Muskrat *Ondatra zebethica*
1
B1
Norway rat *Rattus norvegicus*
Black rat *Rattus rattus*
House mouse *Mus musculus*
Western jumping mouse *Zapus princeps*
Pacific jumping mouse *Zapus trinotatus*
Porcupine *Erethizon dorsatum*
A1B1
Coyote *Canis latrans*
C1
Red fox *Vulpes fulva*
B1
Kit fox *Vulpes macrotis*

Appendix I--*page 11*





N - No range overlap with any oaks

O - No apparent use of oaks despite range overlap

▮▮▮▮- Minor range overlap with oak species

▬- Substantial range overlap with oak species, numerator indicates documented use as cover, denominator indicates documented use as food (1 = light use; 2 = moderate use; 3 = heavy use; A = foliage, roots, fungi; B = mast; C = indirect use)

Quercus
kelloggii

Ecological Relationships Between Southern Mule Deer and California Black Oak[1]

R. Terry Bowyer[2] and Vernon C. Bleich[3]

Abstract: Some ecological relationships between southern mule deer (Odocoileus hemionus fuliginatus) and California black oak (Quercus kelloggii) are examined in the Cuyamaca Mountains, San Diego County, California. Data are presented suggesting that high deer densities adversely affect regeneration of California black oak. Mule deer consume nearly all acorns produced, and have a substantial negative impact on seedlings and sprouts which arise from fallen trees. A hypothesis is advanced to explain the probable evolution of existing deer-oak relationships. The ramifications of the continued decline of black oak stands are discussed.

INTRODUCTION

There is a vast body of literature dealing with the ecology of mule deer (Odocoileus hemionus) in California (for example, see Dixon 1934, Leopold et al. 1951, Linsdale and Tomich 1953, Longhurst et al. 1952, and Taber and Dasmann 1958). Most researchers have noted the importance of oaks (Quercus spp.) in the diet of these ungulates; however, there is little quantified information concerning the impact of deer on oaks. Moreover, the most complete studies have dealt with deer inhabiting the Sierra Nevada and North Coast Ranges, while comparative data for deer occupying ranges in southern California are unavailable. The purpose of this paper is to examine and quantify specific ecological relationships between southern mule deer (O.h. fuliginatus) and California black oak (Q. kelloggii) in montane southern California.

STUDY AREA

This study was carried out on East Mesa, Cuyamaca Rancho State Park, San Diego County, California. East Mesa is located in the Cuyamaca Mountains at an elevation of 1,525 m, and receives approximately 1,000 mm of precipitation annually, including 950 mm of snow fall. Summer temperatures rarely exceed 35°C and winte lows seldom fall below - 10°C.

East Mesa encompasses 800 ha and consists of extensive upland meadows interspersed with thin fingers of oak and pine habitats. The entire area is surrounded by dense, old-growth chaparral. Upland meadows are situated in hydri areas and oak and pine stands occur on rocky, mesic sites. Old-growth chaparral predominates in xeric areas.

The meadows are characterized by annual grasses and forbs, including cheatgrass (Bromus tectorum), ripgut (B. diandrus), six-weeks fescue (Festuca octoflora), red-stemmed filarre (Erodium cicutarium), tumble mustard (Sisymbrium altissimum), western ragweed (Ambrosia psilostachya), and slender-wooly buckwheat (Eriogonum gracile). Deer grass (Muhlenbergia rigens), sedge (Carex sp.), and rush (Juncus sp.) occur in wet portions of meadow habitat. Large concentrations of tumble mustard, a valuable deer forage species, also are found in

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[1] Presented at the Symposium on the Ecology Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] School of Natural Resources, The University of Michigan, Ann Arbor, MI 48109.

[3] California Department of Fish and Game, P.O. Box 1741, Hemet, CA 92343.

meadows with high soil moisture. Wild oats (*Avena barbata*) are common on drier sites adjacent to oak and pine stands. California buckwheat (*Eriogonum fasciculatum*) occurs on the periphery of meadows. Isolated patches of rose (*Rosa californica*) and chokecherry (*Prunus virginiana*) also are present in meadow habitat. Small islands of native perennial grasses, *Agropyron trachycaulum*, *Bromus marginatus*, *Calamagrostis densa*, *Elymus glaucus*, and *Sitanion hystrix*, occur amid broad expanses of annual exotics, but only rarely.

Oak habitat is comprised predominantly of California black oak, but coast live oak (*Quercus agrifolia*) and a scrub form of interior live oak (*Q. wislizenii frutescens*) also are present. Squaw bush (*Rhus trilobata*) and snowberry (*Symphoricarpus mollis*) dominate understory shrubs. Soft chess (*Bromus mollis*) and ripgut occur beneath the oaks and in forest openings. Mexican manzanita (*Arctostaphylos pungens*) and occasionally Jeffrey pine (*Pinus jeffreyi*) also occur in this habitat type. Coffeeberry (*Rhamnus californica*) often inhabits ecotonal zones between oak and meadow.

Pine habitat is composed largely of Jeffrey pine. Within pine stands, California black oak and coast live oak occur at low densities, the latter being more common. Mexican manzanita also is present. Yarrow (*Achillea millefolium*), phlox (*Leptodactylon pungens*), and California brome (*Bromus marginatus*) occur beneath the pines.

Chaparral habitat is characterized by chamise (*Adenostoma fasciculatum*), mountain mahogany (*Cercocarpus betuloides*), mountain lilac (*Ceanothus greggii*, *C. leucodermis* and *C. palmeri*), redberry (*Rhamnus crocea*), holly-leaved cherry (*Prunus ilicifolia*), pink-bracted manzanita (*Arctostaphylos pringlei*), and white sage (*Salvia apiana*).

METHODS

Oak densities were estimated using a combination of toe point (Wood *et al*. 1960) and nearest neighbor (Cottam and Curtis 1956) sampling techniques. Results are based on 1,944 toe points. Diameter at breast height (DBH) and browse line height (BLH) measurements were obtained for 210 California black oaks from seven areas on East Mesa. DBH measurements were made at a height of 150 cm. If an oak branched below that height, only the largest branch was measured. BLH was obtained by recording the lowest new growth available to deer. DBH measurements also were taken from 60 dead California black oaks.

Deer utilization of 93 black oaks was determined by counting the number of "bites" available to deer, and noting the actual number of "bites" removed (Mackie 1970). Furthermore, 200 samples of black oak new growth were clipped, and leader lengths as well as weights of new growth removed by deer were determined.

The abundance and timing of drop for the black oak acorn crop was estimated using five protected 0.22 m^2 plots and 20 unprotected plots of the same size. Data on acorn removal by deer were obtained by sampling within a 49.21 m^2 exclosure that allowed the entry of all wildlife except deer. Estimates of the summer densities of southern mule deer are based on direct observation of 1,401 deer. Plant nomenclature is according to Munz (1974).

RESULTS

Density estimates based on nearest neighbor calculations suggest there are 3,500 California black oaks on East Mesa. In oak habitat, these trees occur at a mean density of 48 oaks/ha, while in pine habitat the mean density is 12 oaks/ha. Approximately 200 southern mule deer inhabit East Mesa.

The most apparent impact of mule deer on black oaks is the conspicuous browse lines on many of these trees (fig. 1). Of the 93 black oaks examined at the end of summer, 96 percent exhibited signs of deer browsing. New growth on the remaining 4 percent of these oaks was too high to be available to deer. Black oaks provided a mean of 289 leaders of new growth available to deer on each tree. Forty-six percent of all available leaders showed evidence of deer utilization. The mean length and dry weight of unutilized black oak leaders were 59 mm and 0.31 g respectively. The mean length and dry weight of utilized leaders were 39 mm and 0.18 g. Thus, deer use of new growth totaled 34 percent by length and 43 percent by dry weight. In

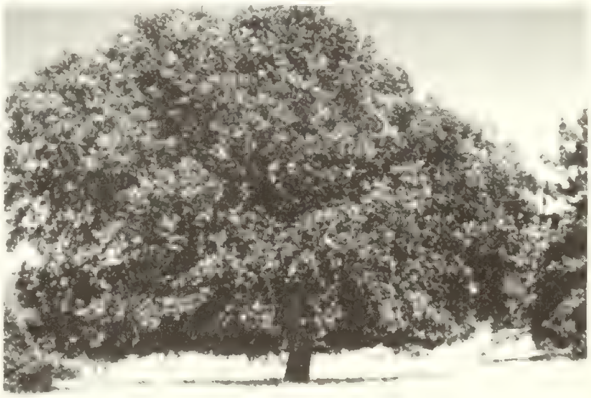

Figure 1--California black oak with a conspicuous browse line from deer overutilization.

aggregate, deer removed 20 percent (by dry wt) of all available new growth. We have calculated that 17 g (dry wt) of new growth per oak, or 58.83 kg (dry wt) of black oak *in toto* were eaten by deer on East Mesa during summer (Jul-Sep). These data suggest that an average deer consumes about 3.2 g (dry wt) of black oak foliage and twigs during this period.

It is evident that black oak stems and leaves are not preferred forage. Almost all browsing by these mule deer occurs during summer when forbs (primarily tumble mustard and red-stemmed filaree) dry out and become unpalatable[4]. Even during summer, southern mule deer take less than 30 percent browse in their diet[4]. Yet, deer densities are sufficiently high that even this low level of utilization causes considerable damage to black oaks. In addition to removing new growth from mature trees, deer adversely affect black oak seedlings. During the spring of 1977, these seedlings numbered 6/ha in oak habitat. However, in areas of heavy deer use, no seedlings survived past early July. Moreover, our data suggest that there has been almost no seedling survival in these oak stands in the last 25 years. Only when acorns germinate within dense patches of squaw bush or snowberry are they not substantially damaged or completely consumed by deer.

Where oak and pine habitats adjoin, pine seedlings, which deer do not eat, are encroaching upon traditional oak habitat. Unless the elimination of black oak seedlings by deer overbrowsing is reduced substantially, the conversion of oak to pine habitat appears to be a strong possibility.

Finally, mule deer influence black oak recruitment by consuming large numbers of acorns. Longtime residents of the Cuyamaca Mountains recall that the 1978 acorn crop is the largest in memory. The majority of black oak acorns was dropped on October 2 and 3, 1978. The number of viable acorns produced during fall is estimated at 6,440/oak or 309,100/ha. Yet, wildlife consumed over 85 percent of this mast by October 20 (fig. 2). All acorns had been removed from the 20 unprotected plots by the end of November (fig. 2). Acorns remaining within the exclosure suggest deer consumed 94 percent of the acorns removed by wildlife. Thus, an average deer ingested approximately 315 acorns/day during fall, which would total 1.21 kg (dry wt)/deer/day. Indeed, acorns are preferred over all other forage, and all deer rumen samples examined during fall contained a large percentage of acorns[4].

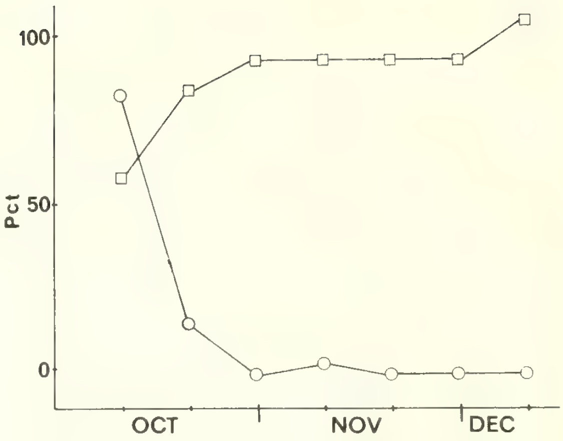

Figure 2--Percentage of total acorns dropped by 10-day periods from 1 October through 10 December, 1978 (open circles), and the cumulative percentage of available acorns removed by wildlife during this same period (open squares).

Root rot (*Armillaria* sp.) is evident on many older black oaks on East Mesa[5]. This condition may predispose these decadent oaks to severe damage during wind and ice storms. Indeed, Staley (1965) has implicated *Armillaria* as a secondary factor contributing to the declin of *Quercus ruber* and *Q. coccinia*. This problem is less pronounced in areas of lower deer densit on East Mesa, as downed oaks typically stump sprout. However, where large numbers of deer occur, these sprouts are eaten back and eventually die.

There was no significant difference (χ^2= 2.35, p>0.05, 1 df) between the mean DBH of living black oaks ($\bar{x}$=63.7 cm) and the mean DBH for dead ones ($\bar{x}$=70.5 cm) throughout oak habitat This suggests that many black oaks may be in imminent danger of being lost from the populatio

The impact of deer on black oak was further assessed by comparing seven areas of varying deer densities with the corresponding DBH and BLH measurements of black oak. Significant positive correlations were found between deer density and both DBH and BLH (fig. 3). Moreover the percentage of black oaks less than 150 cm in height in each area was negatively correlated with deer density, but not significantly (fig. 3 No black oaks less than 150 cm in height were found in areas where summer deer densities exceeded a total of 2.4 deer/ha (fig. 3), which includes all oak habitat on East Mesa.

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[4] Unpublished data, R. Terry Bowyer, School of Natural resources, The University of Michigan, Ann Arbor, Michigan.

[5] Personal communication from Joe Agozino, Resource Ecologist, California Department of Parks and Recreation, San Diego, California.

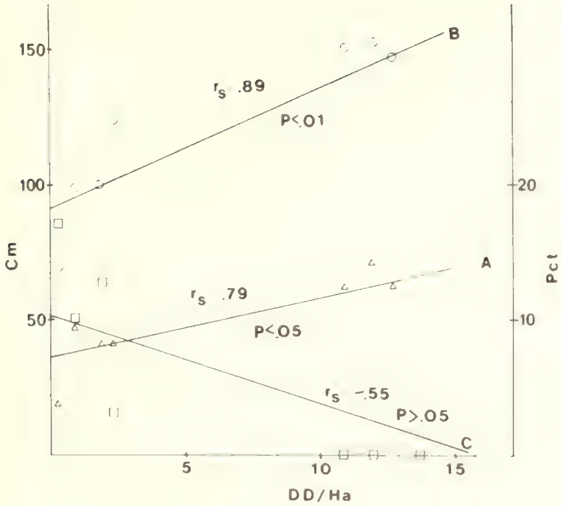

Figure 3--Regressions of DBH (line A, triangles), BLH (line B, circles) and percentage of trees less than 150 cm in height (line C, squares) for California black oak on total deer days of use per hectare (DD/Ha) during summer months. Regression equations for lines A, B, and C are $Y=2.12x +35.66$, $Y=4.34x +90.75$, and $Y= - 0.66x +10.05$, respectively. r_s=Spearman rank correlation.

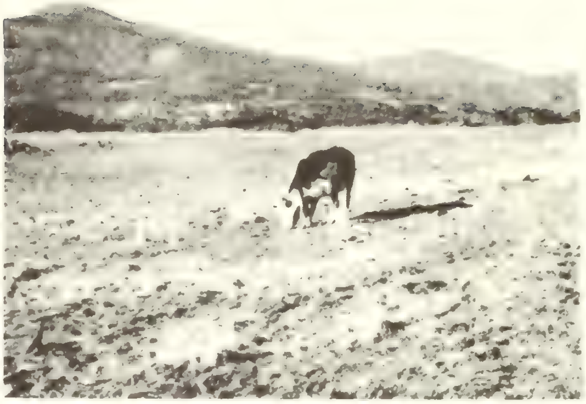

Figure 4--Cattle overgrazing and range deterioration on East Mesa in December, 1955.

DISCUSSION

We hypothesize that the current relationships between southern mule deer and California black oak are linked to environmental changes which occurred approximately 25 years ago. Thus, we have attempted to reconstruct the range history of East Mesa through discussions with long-time residents and Park personnel, and by examining Park files.

Grazing pressure by cattle on East Mesa was relatively light during the first half of the 20th century. But, in the mid-1950's, the original objective of running Cuyamaca Rancho State Park as a cattle ranch was used to secure a lease permitting the grazing of 300 cattle on Park land. The majority of this livestock was pastured on East Mesa. The impact of cattle overgrazing on East Mesa's plant communities was catastrophic (fig. 4). A concerted effort by Park personnel finally resulted in the removal of cattle from East Mesa, but not before overgrazing had wrought dramatic changes. It is likely that this damage to the range contributed to the replacement of native perennial grasses by introduced annual forbs and grasses, as well as leading to tremendous increases in the densities of ground squirrels (Spermophilus beecheyi) and perhaps pocket gophers (Thomomys bottae).

Simultaneously, other environmental permutations were further influencing East Mesa's plant communities. During the late 1940's and early 1950's, wildfires burned vast areas of chaparral adjacent to East Mesa. These fires created large tracts of newly available and productive deer habitat, and likely resulted in a population irruption of these animals. We know of no other environmental changes which might explain this increase in the deer population. However, burned chaparral declines rapidly in nutrient value, and provides suitable deer habitat for only about five years (Biswell 1961, Biswell et al. 1952, Dasmann 1956, and Taber and Dasmann 1958). As the chaparral once again became dense and the shrubs less palatable, it no longer would support this massive number of deer. Thus, we hypothesize an influx of large numbers of deer from the chaparral to East Mesa. Residents of this area recall seeing groups of several hundred deer on East Mesa during this period. Yet, this was considerably more deer than East Mesa was capable of supporting. DBH measurements suggest that the last black oak seedlings in oak habitat were established sometime prior to this period of heavy use by deer and cattle.

The removal of cattle from East Mesa allowed the recovery of plant species which were not preferred by deer. Most spectacular was the rejuvenation of stands of native deer grass which the cattle had nearly eliminated. Unfortunately, the browselines on many shrubs and trees, and the lack of black oak seedlings, went largely unnoticed by Park personnel. Eventually, the deer population came to a new equlibrium at perhaps half its previous size. Today, groups of even 40 deer are observed only infrequently on East Mesa.

The decrease in the deer population from levels attained in the 1950's is probably the major reason for deer damage going unnoticed for so many years. The general opinion was that a decreasing deer population must be well below carrying capacity, and therefore unlikely to cause further serious range problems. But, present deer densities are more than sufficient to prevent black oak regeneration for most areas of East Mesa. Furthermore, the current deer population is probably substantially larger than under pristine conditions. Oak groves on East Mesa are hundreds of years old, and it is difficult to explain the existence of these multiple-aged stands without postulating lower deer densities when they were established. Indeed, Amaral (1978), Peterkin and Tubbs (1965) and Stoeckler et al. (1957) demonstrated that grazing mammals are capable of almost completely preventing regeneration of other tree species.

The ramifications of this decline in the black oak population are enormous. Even if management practices designed to perpetuate black oaks were implemented immediately, the proliferation of multiple-aged stands could take decades. Moreover, the adverse impact of the loss of oak habitat on the myriad of wildlife species that rely on mast for food and/or oaks for nesting and cover (Graves 1977) may be immense.

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Trends in Oak Utilization—Fuelwood, Mast Production, Animal Use[1]

John W. Menke[2] and Michael E. Fry[3]

Abstract: Trends in oak harvest levels in California were shown to be increasing rapidly. The foods produced by oaks, including acorns, leaves, twigs, and lichens,were monitored for two years in blue oak, California black oak, and interior live oak. Oaks were shown to produce quite variable mast crops, whereas crops of leaves, twigs, and lichens were rather steady in quality.

Analyses of deer rumen content showed that deer rely heavily on oak foods in spring, summer, and fall, especially using acorns, when available, from July through October.

Acorns were shown to be an important dietary supplement for sheep, allowing them to maintain their weight when supplemented at a 20% level in the diet or more.

INTRODUCTION

California's oaks (trees and shrubs of the genus Quercus) are a valuable resource that is largely unmanaged. They constitute a critical habitat component for many wildlife species, and, as a source of good quality fuelwood, they are currently of new commercial value in California.

Fuel From Oaks

Figure 1 compares trends in total reported timber harvest in California with trends in reported fuelwood harvest. These data are from annual California Department of Forestry notes on harvest of California timber operators, 1959 to the present. It is assumed that fuelwood consists primarily of hardwood species (oak, tan oak, madrone, and others). Total timber harvest increased steadily between 1947 and 1953, after which there began a long decline. In contrast, the harvest of fuelwood has generally increased since 1959, turning sharply upward in 1973. The average increase in fuelwood harvest reported between 1972 and 1975 was about 38% per year. Reported fuelwood production declined in 1976 and 1977. However, current production remains about 58% above the average annual production reported between 1959 and 1973.

As fuelwood production increased, the cost of fuelwood also rose. From 1944 to 1966 the average price per cord of oak fuelwood was $18, slightly higher if delivered to the buyer's yard (Reveal 1944; Grah 1953, 1955; Gilden 1957, 1959; Dost and Bemis 1966). Today, oak fuelwood harvested in the north coast counties and brought by truck to the San Francisco Bay area is often sold for as much as $100 per cord.

In light of the increased demand for fuelwood and other hardwood products, new emphasis must be placed on the many significant relations between oaks and other forest and range resources.

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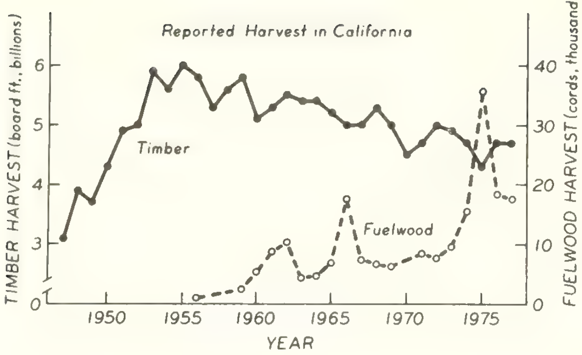

Figure 1--Total timber production as compared with fuelwood production in California.

Utilization of Oaks by Wildlife and Livestock

Several of California's most important game species consume oak browse and acorns to an appreciable extent (Barrett and others 1976, Dixon 1934, Fry and Vaughn 1977, Leach and Hiehle 1957, and Stienecker 1977). Here and elsewhere in the United States the availability of acorns has been correlated with success or failure of reproduction in certain wildlife species (Barrett and others 1976, Burns and others 1954, Korschgen 1955, Matschke 1964).

Van Dyne and Heady (1965) studied the botanical composition of sheep and cattle diets on mature annual range in Mendocino County, California. Leaves and acorns of blue oak (Q. douglasii), black oak (Q. kelloggii), valley oak (Q. lobata) and interior live oak (Q. wislizenii) were found in 60% or more of the diets and composed 4 to 12% of the dietary weight. Longhurst and others (1979) studied the interrelations of deer and domestic sheep in parts of Mendocino and Lake Counties, California, where sheep were found to consume oak leaves and/or acorns nine months out of the year.

Nutritive Quality of Acorns and Oak Browse

Gordon and Sampson (1939) discussed the composition of blue oak acorns relative to other California foothill range vegetation. Wolf (1945) reported the moisture, protein, carbohydrate, fiber, and ash content of acorns of several California oak species. Protein, fat, and tannin values were reported by Dasmann (1971) for four species of western oak. The results of those studies are summarized by Barrett and others (1976). Similar data on oak browse was reported by Makie (1903) and Gordon and Sampson (1939). In general, acorns are shown to be high in carbohydrates and crude fiber, and low in protein and ash. Oak browse is relatively high in both protein and carbohydrates, although the presence of tannin may reduce protein digestibility.

In California, acorns produced by oaks of the foothill woodlands ripen and fall to the ground from late August to November, thereby becoming available to wildlife and livestock at a time when other range forage has matured and lost much of its nutritive quality. The importance of acorns as forage for wildlife and livestock lies in its ability to provide large quantities of energy when other range forage may be low in caloric value.

From 1975 to 1977, studies were conducted at the University of California's Hopland Field Station, Mendocino County, to define further the ecology of oaks on foothill rangelands. This paper presents the following: 1) measurements of acorn production in three oak species; 2) monthly nitrogen and phosphorus levels in oak leaves, twigs, and acorns, plus oak-associated lichens; and 3) data on the use of oak forage by deer and domestic sheep.

STUDY AREA

The University of California's Hopland Field Station is in southeastern Mendocino County on the west slope of the Mayacmas Mountains. Elevations range from 150 to 915 m (500-3000 feet). The dominant vegetation types are oak savannah with an understory of introduced annual grasses, oak woodland, and chaparral. Average annual precipitation of 890 mm (35 inches) falls primarily as rain, between October and March.

METHODS

Acorn Production and Nutrient Analysis

The production of acorns and oak litter was monitored over two years in three oak species (blue oak, California black oak, and interior live oak). Production was assessed with a modification of the funnel-type acorn trap described by Easley and Chaiken (1951) and Gysel (1957). The modified trap consisted of a woven-fence-wire barrel 0.6 m (2 feet) in diameter and 0.9 m (3 feet) high. Steel fence posts were driven into the ground and wired to the trap to prevent disturbance by wind or livestock. The trap was then fitted with a heavy polyethylene liner. The top of the trap was not screened. It was felt that the depth of the trap and the presence of the liner would prevent pilferage by wildlife. Weights were placed in the bottom of the trap to keep the top open during windstorms. Small drainage holes prevented rain water from accumulating.

Trees were selected on the basis of: 1) the species of oak desired; 2) ease of access from main roads; and 3) conformity with typical growth patterns. Traps were placed one per tree beneath the canopy without regard to distance from the bole or aspect (Burns and others 1954, Christisen and Korschgen 1955). Thirty-three traps were divided evenly among the three oak species.

During the first acorn season, traps were visited and their contents collected every one to two weeks. By the end of December of the first year (1975) the interval between collections was extended to four weeks and remained so throughout the remainder of the study. When collected, the contents of each trap were separated and oven-dried at 77 C to a constant weight. The contents of each bag were sorted and weighed into four categories (1) acorns; 2) leaves; 3) twigs; and 4) lichens) and finely ground (30-mesh) in a Wiley mill. Nitrogen levels were determined by the Kjeldahl colorimetric method. Phosphorus levels were determined by atomic-absorption spectrophotometry.

Use of Oak by Deer and Domestic Sheep

The seasonal nature of oak forage use by black-tailed deer (Odocoileus hemionus columbianus) was determined by postmortem analysis of rumen contents of 61 adult deer collected over a period of two and one-half years between the summer of 1975 and fall of 1977. Percent composition (volume basis) of all food items was based upon visual estimates (Korschgen 1962). Recorded values represent the mean percent estimate for a given forage species during a given month. In the raw data, all estimates lower than five percent were recorded as trace (T). In computing the monthly mean values, trace values were treated as zero percent.

The use of oak forage by domestic sheep was studied in a pen feeding trial. The objective was to assess the effect of acorns as a late-season dietary supplement. The trial was designed as a factorial experiment. Thirty-two ewe lambs of the Targhee type were divided randomly among four treatment groups. Each treatment was replicated once. All animals were fed a base ration of maintenance quality (6.15% crude protein) consisting of barley straw (74.4%), alfalfa (21.1%), and molasses (4.5%) in a pelleted form. In addition to the base ration, three treatment groups received acorns at rates of 10, 20, and 30% by weight of total feed allowed per day. The fourth group, a control, received only the base ration. Each animal received three pounds of feed per day. All feed not consumed during a 24-hour period was removed from the troughs and weighed before additional feed was issued. All animals were weighed every seven days, and blood samples taken. Blood was collected from the jugular vein and separated with a centrifuge, and the serum was decanted and frozen. Blood-chemistry parameters studied were blood urea nitrogen (BUN) and blood serum cholesterol (BSC). BUN was measured by the autoanalyzer method of Skeggs (1957) and Marsh and others (1957). BSC was measured by the colormetric method of Zlatkis and others (1953). The trial lasted 41 days.

RESULTS AND DISCUSSION

Acorn Production

Figure 2 summarizes acorn production in the three species studied. In the first year of sampling, blue oak produced many more acorns than either black oak or interior live oak. Sound acorns of all species began falling in late August, but the majority of sound acorns fell in October and November. Seed fall in all cases was lowest in March. In the first year, total blue oak acorn production was 4.80 times that of black oak and 2.75 times that of interior live oak.

In the second year, acorn production declined in all species. Production was greatest by interior live oak, but this species still produced only 57% of the crop of the previous year. Blue oak showed the greatest decline in production, being only three percent of the previous year. Black oak remained the poorest producer in both years.

Immature acorns of black oak and live oak began falling in May. Seeds mature over two growing seasons for these two species, and the early loss of immature seeds in the second year was thought to be due largely to mechanical disturbance of the canopy by wind and rain. Immature and insect-damaged acorns of blue oak, which require a single season to mature, began

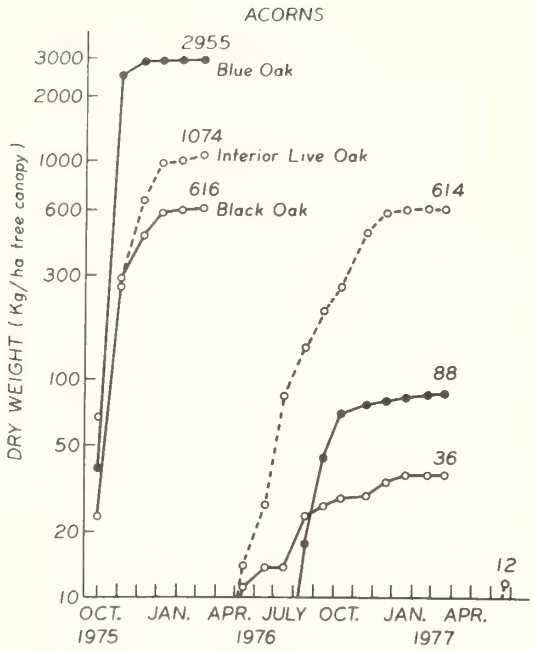

Figure 2--Cumulative (April-March) annual acorn production of blue oak, interior live oak, and black oak canopies (note log scale).

falling in July in the second year. In all cases, as in the first year, the majority of sound acorns fell in October and November.

Acorn productions were largest in 1975, when average blue oak acorn production reached 2955 kg (6515.7 lb) per hectare (2.47 acres) of canopy. The values were lowest in 1976, when average black oak acorn production measured only 36 kg (79.3 lb) per hectare of canopy.

Nutrient Analysis

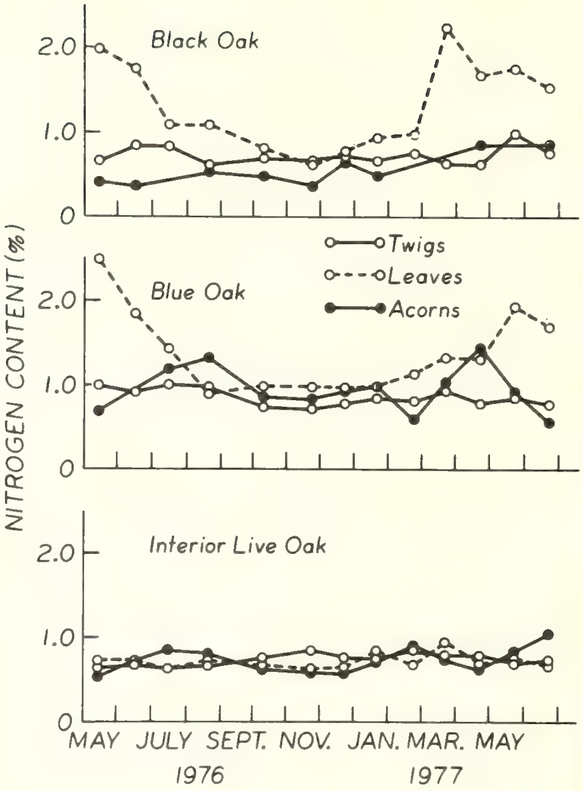

Figure 3--Seasonal nitrogen levels in the twigs, leaves, and acorns, of three oak species.

Figure 3 shows the seasonal levels of nitrogen in oak twigs, leaves, and acorns. These data, derived from samples taken of material falling naturally from the canopies of trees, are therefore of significance more with respect to nutrient cycling than as a measure of forage quality. Nevertheless, with blue oak and black oak, both deciduous species, the nitrogen content of leaves in spring does suggest a significant source of crude protein for ruminant animals. Nitrogen values of two percent and above represent crude protein values of more than 12% (% nitrogen x 6.25 = % crude protein). Crude protein values of this magnitude approach the dietary requirement of adult deer and domestic sheep during gestation and lactation, and therefore are well above the level required for simple body maintenance (Church and Pond 1974, Dasmann 1971). The nitrogen content of the leaves of interior live oak, an evergreen species, varied little seasonally, lacking the high spring peaks found in the deciduous species. The highest values were recorded from spring samples, but these did not exceed the one percent level. The year-long crude protein content of live oak leaves remained below seven percent. The nitrogen content of twigs and acorns varied little and remained low throughout the year in all species.

Figure 4 shows the seasonal phosphorus content of oak leaves, twigs, and acorns. Phosphorus levels showed two annual peaks, one in spring and one (less pronounced) in late fall. This was true for all three species but was most prominent in the deciduous oaks. Blue oak and black oak leaves showed phosphorus levels exceeding 0.1 percent throughout most of the year. Phosphorus levels exceeding 0.2 percent

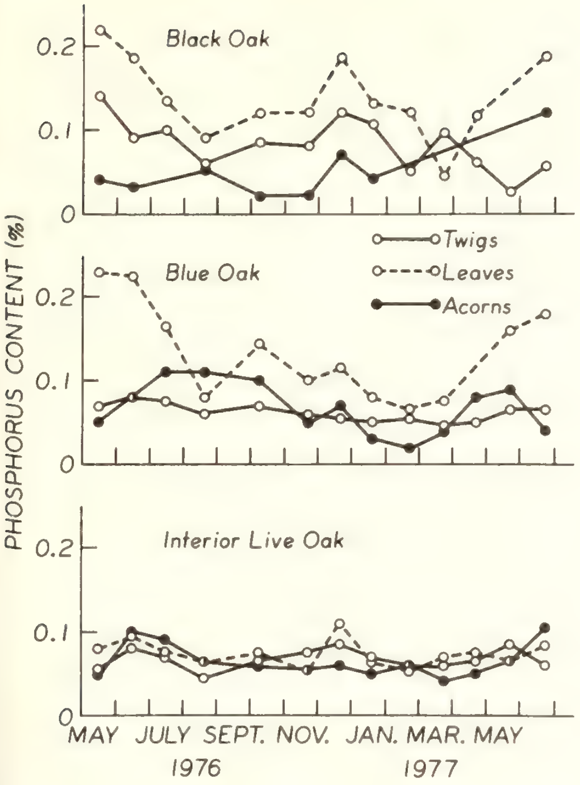

Figure 4--Seasonal phosphorus levels in the twigs, leaves, and acorns of three oak species.

were recorded in the spring. Phosphorus levels of 0.16 percent are considered adequate to meet the gestation requirements of domestic sheep and are probably adequate for deer as well. The phosphorus content of twigs and acorns was generally lower than that for leaves in all three species. Live oak phosphorus levels were generally lower than either blue oak or black oak in all sample categories throughout the year. The spring and late-fall phosphorus peaks in live oak reached only slightly more than 0.1 percent.

Figure 5 shows monthly nitrogen and phosphorus values derived from a pooled seasonal sample of oak-associated lichens. Genera represented in the sample include Ramalina, Evernia, Parmelia, and Usnea. The seasonal nitrogen content of lichens remained very stable. No perceptible spring nitrogen peaks were observed. Nitrogen levels remained at about 1.5 percent throughout the year. Lichens thus represent a potential crude protein source of about nine percent for ruminant animals.

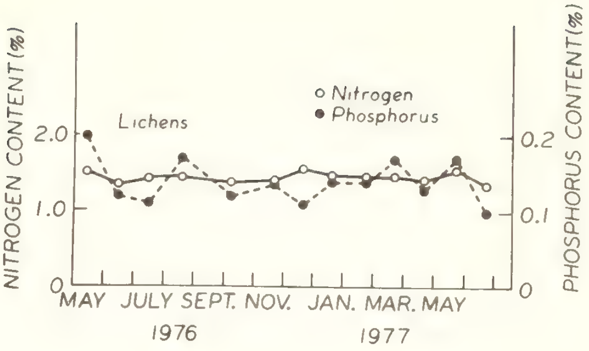

Figure 5--Seasonal nitrogen and phosphorus levels in lichens falling from oak tree canopies.

Phosphorus levels in oak-associated lichens were similar to those in the leaves of deciduous oaks. Spring values reached 0.2 percent. Values fluctuated over the remainder of the year but did not fall below 0.1 percent. There was no late fall peak in the phosphorus content of lichen as observed in the leaves, twigs, and acorns of oak.

Deer Use of Oak Forage

Rumen content analyses showed the use made of oak browse (leaves and twigs) in all months of the year (table 1). Average monthly consumption of oak browse by deer ranged from 2.5 percent (in March) to 50.2 percent (in August). Year-long consumption of oak browse averaged 21.5% per month. The frequency of occurrence of oak browse in deer diets expressed on a seasonal basis is shown in Table 2. Oak browse occurred most frequently in summer diets (100%) but was also very prominent in fall diets (91.6%). Although 75% of spring and winter diets contained oak browse, the actual quantities consumed were lower than in summer and fall diets. Winter diets contained up to 10% oak browse, and spring diets had up to 30%. In contrast, summer diets contained up to 85% oak browse and fall diets up to 60%.

Acorns in quantitites of 5 percent or more appeared first in samples collected in July. Quantities consumed and frequency of occurrence increased through October and then dropped sharply (table 1). Trace amounts were recorded in December, January, and March samples. Acorns were absent from spring diets. The greatest quantities of acorns were present in samples collected in September. Of the six samples analyzed for September three contained acorns in amounts

Table 1--Food habits of Columbia black-tailed deer, Hopland Field Station, Mendocino County, California.

FOOD ITEM	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Acorns	T		T				2.5	14.6	38.3	33.3	6.9	T
Oak leaves and twigs	5.0	2.6	2.5	3.4	14.0	35.0	41.3	50.2	29.8	29.9	29.3	15.0
Blue oak	2.5		T				14.4	15.0	0.8	7.5		5.0
Black oak	2.5			T			6.9	17.0	0.8	10.0		
Interior live oak			0.8	1.7	2.0		3.1	3.9	T	5.8	10.3	5.0
Unid. + other oak		2.6	1.7	1.7	12.0	35.0*	13.8	13.7	28.2	10.0	18.9	5.0
Other woody plants	55.0	53.9	14.1	26.6	7.0	35.0	15.6	11.3	9.2	6.7	26.0	16.6
Grasses	27.5	41.0	61.7	35.8	22.0	15.0	28.8	14.6	20.0	25.8	27.5	46.7
Filaree		1.3	15.0	12.5	18.0	T	2.5	T		2.5	6.9	18.3
Legumes		T	2.5	8.3	22.0	15.0	T	T	1.7	T	T	T
Other forbs		T	0.8	6.6	15.0	T	1.9	T	0.8	T		T
Lichens	T	1.3	3.3	6.7	2.0		6.3	6.3	T	0.8	3.4	T
Fungi	12.5	T	T	0.8			0.6	0.5	T	T	T	3.3
Total % composition of major food items	100	100	99.9	100	100	100	99.5	97.5	99.8	99	100	99.9
Number of samples	2	4	6	6	5	2	8	10	6	6	3	3
Number of forage items (includes trace items)	14	15	20	23	27	11	37	35	24	28	19	15

* All scrub oak (Q. dumosa).

Table 2--Frequency of occurrence of oak browse and acorns in the seasonal diet of black-tailed deer, southeastern Mendocino County, California.

Food Item	Spring (April-June)	Summer (July-Sept.)	Fall (Oct.-Dec.)	Winter (Jan.-Mar.)
Oak browse	75%	100%	91.6%	75%
Acorns	0%	87.5%	75%	16.6%
No. of samples	13	24	12	12

of 85, 90, and 100% by volume. October rumen samples also contained large quantities of acorns.

Frequency of occurrence of acorns in October diets was 100%, with quantities ranging from 10 to 20% by volume.

Figure 6 shows the average seasonal composition of deer diets on the Hopland Field Station as determined through rumen content analysis. In winter, deer relied upon other forms of woody browse and grass and showed little use of oak. Small quantities (5% or less) of cured leaves from deciduous oaks (black oak, valley oak, and blue oak) were found in the diet at this time of year, and only trace amounts of acorns. Dixon (1934) also reports the use of cured black oak leaves by deer in California.

The spring diet was very diverse, with forbs constituting the largest single forage category, and nearly equal amounts of grass, oak browse, and other woody browse were consumed. The most prominent species of oak in spring diets were chaparral oak species, scrub oak (Q. dumosa), and shrub live oak (Q. wislizenii var. frutescens). Acorns were entirely lacking.

In the summer, deer showed a strong preference for oak browse and acorns. These two forage items together constituted about 60% of the diet. Woodland oak species constituted the majority of the oak forage component. Seven species of oak forage were found in summer diets.

Fall diets contained less oak browse and fewer acorns than summer diets; however, these two forage items combined provided 36% of the dietary volume.

Sheep Feeding Trial

Table 3 summarizes average weekly weight gain, blood urea nitrogen and serum cholesterol values observed in 32 ewe lambs fed various levels of acorns during a 41-day feeding trial. The control group, which received only the base ration with no acorn supplement, lost weight at the rate of nearly one pound per animal per week (-0.86 lb/wk). Treatment group one (10% acorn supplement) also lost weight, although less than the control group (-0.18 lb/wk). Treatment group two (20% acorn supplement) showed no weight change, while treatment group three (30% acorn supplement) gained weight at 0.32 lb/wk.

Blood urea nitrogen (BUN) and serum cholesterol are used as indicators of condition in ruminant animals. BUN reflects generally the amount of digestible protein in the animal's diet, whereas serum choles-

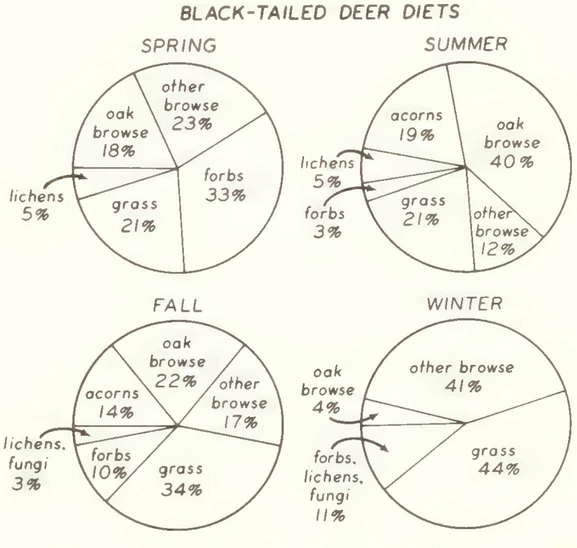

Figure 6--Average seasonal dietary composition of deer on the Hopland Field Station.

Table 3--Average weekly gain, blood urea nitrogen, and serum cholesterol values of sheep fed various levels of acorns during a 41-day feeding trial.

Response	Acorn supplement level (percent of diet)			
	0	10	20	30
Average weekly gain (lbs/wk)	-0.86	-0.18	0.00	0.32
Average blood urea nitrogen (mg %)	15.3	15.2	12.8	12.0
Average serum cholesterol (mg/dl)	82.3	83.4	90.6	92.4

terol is a measure of the energy component (i.e., fats and carbohydrates). BUN values were highest in the control animals and declined with increasing acorn supplement. Serum cholesterol values were lowest in the control animals and increased as acorn supplement increased. The inverse relation of BUN and serum cholesterol was believed to be a function of the low-protein, high-carbohydrate, and solid-fat composition of the acorn. In addition, the presence of tannin in acorns may reduce protein digestibility.

Since acorns may make up 15-20% or more of the diet of black-tailed deer in summer and fall, this food resource is clearly an important one. An intake level of 20% or more in the diet appears to be adequate for yearling sheep to maintain their body weight while seasonal forage conditions are poorest. The value of acorns in the diet is probably at least as great in deer as it is in sheep.

SUMMARY AND CONCLUSIONS

Fuelwood harvest, including oaks, has generally increased since 1959, turning sharply upward in 1973. The average increase in fuelwood harvest between 1972 and 1975 was about 38% per year, and with increasing energy costs greater harvests are probable.

Blue oak, California black oak, and interior live oak production of acorns and litter (leaves, twigs, lichens) were monitored for two years. During a good mast year,blue oak, interior live oak, and black oak respectively produced 2955, 1074, and 616 kg/ha of tree canopy; while during a poor year they respectively produced 88, 614, and 36 kg/ha of tree canopy. Nutrient-content analyses showed that oak leaves and twigs can supply the dietary requirements of ruminants for protein and phosphorus in spring and fall and that oak-associated lichens supply a rather steady year-long 9% crude protein source.

Rumen-content analyses on 61 black-tailed deer showed that acorn quantities in the diet of 5 percent or more appeared first in July, and quantities and frequency of occurrence increased through October and dropped sharply in November. Oak-associated foods accounted for more than 60% of the deer's diet in summer and more than 36% in fall on the Hopland Field Station.

Thirty-two yearling ewe lambs were fed 0, 10, 20, or 30% of their diet as acorns in a 41-day feeding trial simulating fall field conditions. Acorns were shown to be a valuable dietary supplement since animals in the zero-level group lost 0.86 lb/week while animals in the 30% acorn supplement group gained an average of 0.32 lb/week. The high-carbohydrate and solid-fat composition of the acorn, as well as high tannin level, was suggested as the reason for the inverse relation between blood urea nitrogen and serum cholesterol responses over the range of acorn supplements fed.

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Quercus douglasii

Livestock Utilization of California's Oak Woodlands[1]

D. A. Duncan[2] and W. J. Clawson[3]

Abstract: California's oak woodlands are important to the range livestock industry. Among interactions between oaks and livestock are effects of grazing on oak regeneration and the canopy effect of oaks on the herbaceous understory. Oak leaves and acorns vary in value according to species and other factors, as browse and food for livestock and wildlife.

Key words: Oak woodlands, livestock utilization, browse, mast, range livestock

INTRODUCTION

The oak woodlands of California are an important source of range forage for the State's livestock industries, even though the oaks themselves play a minor role. It is estimated (Biswell 1956) that out of the 17.5 million acres which provided 80 percent of the forage for domestic livestock raised on California wildland, 7.5 million acres were woodland-grass. In addition, some 3 million acres of woodlands are usually dominated by oaks. The total of more than 10 million acres of oak woodlands, a figure which corresponds to other estimates in the literature (Wieslander and Jensen 1946), include the foothills, which have been referred to as "the most important range area within the State" (Bentley and Talbot 1951).

The San Joaquin Experimental Range (Madera County) includes areas typical of much of the California oak woodlands, which have been described as being "in the lower portion of the woodland zone between the treeless plains below and the higher brushy and timbered belts" (Hutchison and Kotok 1942). It is "open and everywhere accessible to livestock...with scattered trees and bushes, and occasionally dense clumps of shrubs. The lower ground cover, consisting chiefly of annual grasses and herbs...is made up of a large number of different species." This description applies to much of the California oak woodlands.

The oak woodlands have been historically linked with California's vast livestock industry. The early Spanish missions and rancheros were often located in the oak woodlands of the Coast Range. After the discovery of gold in the western Sierra foothills, the oak woodlands again supported an expanding livestock industry to supply meat to the miners, as homesteads and ranch developments spread throughout the State.

REGIONAL DIFFERENCES

A recent treatment of California's oak woodlands by Griffin (1977) provides an excellent summary of knowledge of the area and its regional differences. Earlier, based on the "plant communities" of Munz and Keck (1959), Griffin and Critchfield (1972) identify three oak woodland associations--foothill woodland, northern oak woodland, and southern oak woodland. The northern oak woodland of the north Coast Ranges is characterized by the presence of the Oregon white oak (Quercus garryana), with an associated livestock industry comprised of both sheep and cattle producers operating the year around. At the other end of the State, the southern oak woodland is characterized by the presence of the Engelmann oak (Q. engelmannii) and coast live oak (Q. agrifolia) and much of it is not grazed. The relatively small livestock industry is mainly beef cattle production including both year-round cow-calf and seasonal stocker operations.

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The foothill woodlands are more extensive and cover a vast area of the great Central Valley and lower elevations of the Coast Range. Blue oak (Q. douglasii) and digger pine (Pinus sabiniana) characterize the community, with neither species ranging far beyond this particular type (Griffin and Critchfield 1972). There are many other species of oaks present, including the valley oak (Q. lobata) and interior live oak (Q. wislizenii) in the north, coast live oak in the south coast, and California black oak (Q. kelloggii) at higher elevations. The livestock industry in the south Coast Ranges is centered around beef cattle production involving both year-round, cow-calf, and seasonal stocker operations. The foothill woodlands of the western Sierra foothills have historically been used on a seasonal basis rather than for year-round operations. These have been heavily used during the winter and spring flush of growth; the cattle have been moved to the upper elevations, mostly on Federal grazing permits, or to irrigated and dryland pastures down in the Central Valley. Livestock production, again, is primarily beef cattle, with more stocker cattle present in the southern foothills than in the north. Another distinctive type of livestock operation occurs in the northern and northwestern foothills of the Sacramento Valley. Both sheep and cattle are grazed in this area during the winter and spring growing season. The livestock are transported to southern Oregon or to the Sierra-Cascade mountain ranges during the summer and early fall.

Although cattle are now the most important, other species of livestock also use California's oak woodlands. Many of the horses in California are in the oak woodlands area; they are used in livestock operations and, increasingly for pleasure. In swine production, acorns were utilized until economic factors curtailed this type of extensive management. The Madera County Historical Society (1968) notes, "At the time placer mining first penetrated the area, farming and ranching were already becoming established. Hogs evidently were more important than cattle until barbed wire was available in the mid-1870's, making large cattle herds more practical. Sheep, however, were more numerous than cattle through the 1880's." Now wildhog hunting ranks second in popularity among California's big game animals. Wildhog habitat is often associated with the oak woodlands (Barrett 1978). Of a relatively small number of range goats in California (Spurlock and others 1978), there are probably more in the areas of heavy brush than in the oak woodlands.

Man's search for desirable places to live is probably the greatest constraint on use of the oak woodlands for livestock production. The climate and scenic beauty of the oak woodlands make them highly attractive for human habitation. It is estimated that Madera County has lost at least 10 percent of its oak woodlands to subdivisions (McDougald 1979). As one travels the central coast or the Sierra foothills, this settlement pattern is seen repeating itself. Many other land uses (military reservations, water storage, natural preserves, etc.) limit opportunities for grazing on the oak woodlands.

Most quantitative information relating livestock production to the oak woodlands comes from three experimental areas. The oldest is the San Joaquin Experimental Range which was established in 1934 by the Forest Service, U. S. Department of Agriculture. The University of California, Division of Agricultural Sciences, operates the Hopland Field Station, established in 1951, and the Sierra Foothill Range Field Station, established in 1964. Summaries of the livestock research and a list of publications for the San Joaquin Experimental Range are found in Wagnon and others (1959) and Duncan (1975), and for Hopland in California Agriculture (Univ. Calif. Agric. Exp. Stn. 1976).

OAKS AND LIVESTOCK

Oaks and livestock affect each other's welfare in many ways. For example, oaks serve as a source of shade for domestic livestock during hot weather. The need for shade is well known (McDaniel and Roark 1956), but is difficult to quantify in terms of animal production and will not be discussed here.

Regeneration

The browsing of young trees by livestock has often been cited as the cause of poor or no oak regeneration. Exclusion of cattle in several instances for a rather long period did not bring about any instant oak regeneration, however. A considerable increase in digger pine and buck brush (Ceanothus cuneatus) was noted in the Natural Area at the San Joaquin Experimental Range, which has been protected from grazing and fire since 1934, (Woolfolk and Reppert 1963), but no increase in oaks was reported. Photographs indicated extremely little change in older blue oaks over periods of more than 20 years. In another paper in this Symposium, Griffin noted exclusion of cattle on the U. C. Hastings Natural History Reservation in Monterey County did not result in oak regeneration.

In discussing lack of the blue oak seedlings and young trees in Kern County, Twissleman (1967) reasoned that poor oak reproduction was probably a combination of drought, livestock browsing, and the inability of young seedlings to compete with introduced annual plants. He suggested prolonged drought might be the most significant of the above factors.

The effect of combined sheep and deer use on oak regeneration at the Hopland Station was discussed by Longhurst and others (1979). After only 5 years of protection 554 oak seedlings were counted per acre, compared to none in the grazed area. The authors conclude that "with virtually no replacement of oak stands under the combined weight of deer and sheep use, this important source of browse and mast will gradually be reduced as trees mature and die."

There is no doubt that consumption of acorns by domestic livestock and many species of wildlife greatly reduces the number of acorns that might possibly become trees. In addition to acorn use by domestic animals, which will be discussed in more detail, acorns are very important diet items for quail and ground squirrels (Glading and others 1940, Shields and Duncan 1966, Schitoskey and Woodmansee 1978).

Observations of recent events on the San Joaquin Range provide an example. A severe drought in 1977 resulted in scanty forage, but blue oaks produced a good crop of acorns. Ground squirrels were repeatedly seen securing acorns up in the oaks in an ungrazed area; the few acorns that reached the ground were consumed by deer. Although the following year was wet, few seed were left for oak regeneration.

Canopy Effect on Forage

In many foothill areas in central California, the difference in amount and kind of herbaceous vegetation under the canopy of oaks, especially blue oak, is readily apparent even to the casual observer, especially in the winter and early spring. The canopy effect of the various oaks of course varies regionally, and definitely is influenced by the density of the oak trees. A summary of work in northern California, noting that removal or reduction of blue oaks increased forage production, is presented by Kay and Leonard in a paper in this Symposium. A discussion of the effects of blue oak on forage production and nutritional quality in central California may be found in the Symposium papers of Holland, and Holland and Norton, and the picture is quite different from areas studied by Kay and Leonard. In earlier reports, Holland (1973, 1976), noted that in central California herbaceous vegetation production was 40 to 100 percent greater under blue oaks than in open grasslands. Many of the data in Holland's reports were collected on the San Joaquin Experimental Range in Madera County. In a severe drought year on the Experimental Range considerably more herbage was noted under the blue oak canopies than in open areas (Duncan and Reppert 1960). This was confirmed over a period of seven years, and herbage growth was observed to begin earlier, and plants to stay green longer, underneath blue oaks (Duncan 1967). Also, observations and utilization records showed that cattle preferred forage under blue oaks, both in green and dry seasons. Discussion with ranchers indicate that in some other areas of the State, cattle apparently do not show this preference.

OAKS AS BROWSE AND MAST

It is difficult to estimate the value of the oak species as browse. Sampson and Jespersen (1963) pointed to the difficulty of identifying the oak species of primary browse importance because grazing animals in different situations vary in their choice of species. Interior live oak, California scrub oak (Q. dumosa), blue oak and California black oak were seen as being the more palatable in most situations, however. Listed as secondary are the Oregon white oak, canyon live oak (Q. chrysolepis) and huckleberry oak (Q. vaccinifolia). The food value of coast live oak and valley white oak is probably mainly in the acorns. Browse ratings of several oak species are listed for domestic livestock and deer (table 1).

An estimated 1 to 2 percent of the forage utilized by domestic livestock year after year was obtained from all browse plants on the San Joaquin Experimental Range (Hutchison and Kotok

Table 1--Summary of browse ratings of oak species for domestic livestock and deer[1/]

Species (Quercus)	Common Name	Overall Browse Value[2/]				
		Cattle	Horses	Sheep	Goats	Deer
Q. agrifolia	Coast live oak	5	5	4-5	4-5	3-4
Q. chrysolepis	Canyon live oak	5	5	5	5	3-4
Q. douglasii	Blue oak	4	4-5	3-4	3-4	1-2
Q. dumosa	California scrub oak	4-5	5	4	2-4	1-2
Q. garryana	Oregon white oak	4-5	5	4-5	4-5	2-3
Q. kelloggii	California black oak	2-4	4-5	3-4	3-4	1-2
Q. lobata	Valley white oak	4	5	4-5	4-5	3-4
Q. vaccinifolia	Huckleberry oak	4-5	5	4-5	4-5	3-4
Q. wislizenii var. frutescens	Scrub interior live oak	4	5	3-5	3-4	1-2

[1/] Adapted from Sampson and Jespersen 1963.

[2/] Overall rating symbols are: 1 = excellent, 2 = good, 3 = fair, 4 = poor, 5 = useless.

1942). These species do provide some green material as a source of protein, phosphorus, and possibly vitamin A during the summer when the herbaceous forage is mainly dry. The species most commonly browsed are the California blue oak, interior live oak, and California buckeye (Aesculus californica), in that order.

Hopland Field Station sudies (Van Dyne and Heady 1965) with sheep and cattle during the months of July, August, and September indicated that more than 5 percent of the field-harvested forage in late summer was fallen leaves and acorns of Quercus species, which occurred in 60 percent or more of the animal diets and composed 4 to 12 percent of the diet by weight. Sheep diets in the late summer frequently contained newly-fallen acorns, and field observations indicated that both cattle and sheep browsed on the low-hanging branches and on fallen twigs and leaves. The Hopland pastures had been grazed by sheep for several years, so that there was a browse line at approximately 4 feet. Thus, it would appear that more browse was available to cattle than to sheep, but on the average cattle and sheep selected about the same amount.

Also reporting on work at the Hopland Station, Longhurst and others (1979) presented findings on the use of oak mast and leaves by the range herbivores, on mast production, and the effect of the grazing animals on oak regeneration. In general, they found deer consumed more acorns and relied more on browse than sheep. For a 5-year period, average acorn production from blue oak trees was about 13 lb/per tree/per year, and the amount of acorns by year varied from less than 2 lb to over 55 lb/per tree. Similar wide variations in acorn production have been observed by workers at the San Joaquin Experimental Range. More detailed treatments of mast production and/or animal use are presented by Menke and Fry, and by Graves in other Symposium papers. Barrett (1978) lists acorns as the most important food item of feral hogs inhabiting oak woodland in the Sierra foothills.

On the San Joaquin Experimental Range, cattle definitely do browse to some extent on the oaks, and seem to prefer blue oak to interior live oak. Observations by the senior author indicate the opposite preference is shown by deer. Hutchison and Kotok (1942) and Wagnon and others (1959) have surmised browsing of oaks and other woody vegetation results in adequate provision of vitamin A even in periods when there is no green herbaceous material available.

In the central part of the State's oak woodlands, both domestic livestock and many species of wildlife consume acorns when available. Considerable attention has been paid to acorn use by cattle because of an abnormal congenital condition, described by Hart and others (1932) which has existed in cattle on the foothill ranges for many years. The deformity is more common in the oak belt, and usually occurs in poor feed years; the name "acorn calves" for deformed animals originated from the general impression that the deformities resulted from the dams' consuming excessive amounts of acorns during the gestation period. In describing early acorn-feeding trials at the San Joaquin Experimental Range, Wagnon and others (1942) stated their preliminary results indicated acorns were not the primary factor in causing "acorn calves".

In a bulletin entitled "Acorn Calves", Hart and others (1947) reported on long-term studies and said the name was incorrect. They concluded that examination of fifteen years of data on acorn calves showed the condition is nonhereditary, and that it is due to maternal nutritional deficiency, probably occurring between the third and sixth month of gestation. They also stated the specific deficiency or deficiencies involved had not been ascertained. Since the acorn calves had occurred without the dams' having access to acorns, it was evident that their ingestion was not the direct causative agent. They concluded by stating, "Acorns may be a contributing factor, however, when they are the main ingredient of the diet, by preventing the formation or utilization of some dietary essential. A consistent, constructive policy of livestock management, with supplemental feeding that will enable the breeding cows to produce maximum percentage calf crops and calves of optimum weaning weight, can be counted on practically to eliminate acorn calves."

Reporting on early acorn-feeding trials at the San Joaquin Experimental Range, Wagnon and others (1942) noted marked differences in the palatability of acorns from different live oak trees in 1936. In August, consumption of acorn was 3 or 4 pounds per day, and by September, cows were eating 14 to 18 pounds per head daily Consumption increased to as much as 37 pounds per day for one cow. In describing the reasons for a series of studies on acorns as cattle fee Wagnon (1946) noted that of the various species of trees on California rangelands oaks are easily the most abundant, and the occasional large crops of acorns are readily eaten by rang cattle. These years of heavy mast have been of concern to many stockmen, and among the deleterious effects attributed to heavy feeding on acorns are deformed calves, abortions, death from impaction, and weight losses. Wagnon noted, however, that some cattlemen claim that the cattle gained weight. Usually the greatest weight losses occurred in cattle consuming acorns just prior to the onset of winter, when feed conditions were poor. He summarized the chemical content of acorns of several oaks (table 2), and his studies demonstrated that heavy ingestion of low-protein acorns when the

Table 2--Chemical analysis of acorns from five different species of oak[1]

	Blue oak *Quercus douglasii*	Live oak *Quercus wislizenii*	Black oak *Quercus kelloggii*	Valley oak *Quercus lobata*	Scrub oak *Quercus dumosa*
	Percent				
Moisture	40.75	29.80	37.60	40.57	44.58
Crude Protein	3.03	3.08	3.43	2.82	2.29
Crude Fiber	7.08	11.24	14.07	7.84	7.96
Fat	4.77	14.47	11.05	4.25	3.42
Nitrogen-free Extract	43.39	40.40	32.71	43.44	40.65
Ash	0.98	1.01	1.14	1.08	1.10
Calcium	0.08	0.09	0.09	0.08	0.09
Phosphorus	0.04	0.05	0.06	0.06	0.05
Tannins	3.61	4.60	1.81	3.85	5.15

[1] From Wagnon 1946.

forage was dry and also low in protein resulted in rapid weight loss. However, providing a protein supplement counteracted any ill effects and promoted gains when the forage was poorest. When green forage was available, acorns gave good results. He summed up his results as, "Thus with adequate supplemental feeding, acorns can become a very important feed resource instead of a decided liability."

Wagnon (1960) described a series of studies in which cattle were fed oak leaves in addition to acorns, to gain insight into the old question and differences of opinions among stockmen whether acorns were harmful or good cattle feed. Results were not conclusive, but providing a protein supplement to range cows grazing on dry forage and eating blue oak acorns resulted in weight gains as he had reported earlier (Wagnon 1946) and cows receiving no supplement lost weight.

Gordon and Sampson (1939) noted that the crude protein content of blue oak leaves on the San Joaquin Experimental Range varied from 30 percent for young leaves to 10 percent for mature leaves. However, Sampson and Jespersen (1963) assigned the blue oak a "poor" browse rating for cattle. No ill effects from feeding blue oak leaves were reported by Wagnon (1960), but he noted that the study animals would not eat the leaves from certain trees. Similarly, they ate acorns from some trees readily, but not those from others.

In a comprehensive report on the behavior of beef cows, Wagnon (1963) noted they spent about 18 percent of the feeding time beneath canopies, as compared to 60 percent on open slopes and 22 percent in swales. He determined that browsing was of practically no importance when green forage was abundant and of minor importance as a source of feed the rest of the year. Animals spent less than 4 percent of the total feeding time browsing.

MANAGEMENT IMPLICATIONS

In addressing the question, Can California's oak woodlands be managed for sustained yield?, in this paper, we must look at the sustained yield in terms of livestock utilization of the oak woodlands. There is seldom a simple answer to a complex biological/sociological/economic question, and blanket statements can always be picked apart. In general, however, livestock use of California oak woodlands can probably continue at today's levels without jeopardizing the oak stands. And, with present technology, livestock production could probably be increased. Overall production of livestock in the area probably is, and will be, decreased more by loss of grazing lands to other land uses than by overutilization by domestic livestock and wildlife.

The exclusion of grazing on many acres of the oak woodlands calls attention to one good effect of livestock utilization that is commonly overlooked. This is the reduction of the fuel build-up. Those of us who live in the tinder-dry foothill areas every summer shudder at the idea that the mass of herbage that grows each year should not be used by livestock. The problem of fuel build-up has become more noticeable in recent years as increasing acreage in the oak woodlands has been sold, subdivided, or otherwise removed from grazing. More and more people are moving into areas where more and more fuel is available to carry wildfires.

The effect of oak tree canopy has been treated briefly here. The decision to remove, or thin, or leave oaks undisturbed depends on the objectives of the landowner or manager, and the particular combination of climatic, edaphic, and vegetative features of each individual area. Economic considerations usually enter the picture. But, one thought should be kept in mind--removal of an old oak tree, though perhaps not permanent, has long-lasting effects on the people and all other organisms in the immediate vicinity.

The sustained yields of the oaks themselves are covered only indirectly in this paper. Perhaps the "whys" of little or no oak regeneration in some areas have been brought into focus by this Symposium. Hopefully the interchange of facts, ideas, and opinions will help us make better informed decisions leading to more rapid strides in gaining a realistic understanding of the problem, what is causing it, and in developing ways of obtaining oak regeneration where desired.

California's oak woodlands have been, are, and probably will continue to be an important area in which the range livestock industry can, under proper management, produce a considerable proportion of the food and fiber products needed to meet the demands of the population of the State.

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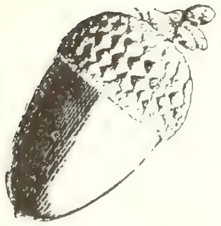

Quercus douglasii

Effect of Blue Oak on Rangeland Forage Production in Central California[1]

V. L. Holland [2]

Abstract: Evidence presented in this investigation indicates that the current practice of eliminating blue oaks to increase rangeland forage is not a beneficial management practice. Forage production under blue oaks is often double that of adjacent open grassland. Furthermore, after the trees die or are killed, forage yields decrease to levels comparable to the less productive open grassland. The increased forage yield under blue oaks indicate that in order to maintain current rangeland production, existing trees should be preserved. Finally, a management plan should be implemented to assure successful future reproduction of blue oaks.

INTRODUCTION

Blue oak (Quercus douglasii H. & A.) is a deciduous white oak (subgenus Lepidobalamus) endemic to California. It is the main tree species on several million hectares of land and covers an estimated 6.5 percent of the land area of California (Murphy and Crampton 1964). Restricted to the rather dry foothill woodland regions of California, its distribution pattern forms a ring around the Central Valley (Griffin and Critchfield 1972).

Some range managers consider blue oak undesirable in areas used for cattle or sheep grazing. One of the main reasons is that blue oak reportedly reduces the quality and quantity of forage growing beneath the trees (Murphy and Berry 1973, Murphy and Crampton 1964, Johnson et al. 1959). As a result, these investigators have advocated eliminating blue oak from foothill rangelands as a means of increasing livestock forage. The elimination of blue oak has occurred over thousands of hectares of land by bulldozing, burning, girdling, cutting (and used as cord wood), or by chemical treatment with 2, 4-D and 2, 4, 5-T applied in axe cuts or even by aircraft sprayin (Leonard and Harvey 1956, Leonard 1956, Johnson et al. 1959, Murphy and Crampton 1965, Dal Port and Carlson 1965, Murphy and Berry 1973).

In contrast to these previous studies, observations in many areas of California indicate clearly that forage production is greater under blue oaks than in open grassland. This paper reports the results of an investigation carried out in the foothills of the centra Sierra Nevada and South Coast Ranges on the effects of blue oak on rangeland species composition and forage production. Also discussed is the change in forage production and composition after a tree dies. Nutritional quality of the forage is discussed in a companion pape (Holland and Morton 1979).

STUDY AREAS

Forage production under blue oak trees (both living and dead) and in adjacent open grassland was measured in detail at the U.S. Forest Service San Joaquin Experimental Range (Madera County) and the U.C. Hastings Natural

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[1] Presented at the Symposium on Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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History Reservation (Monterey County). Forage production of two other sites was measured in San Luis Obispo and Kern Counties with essentially the same results (Holland 1973) but are not discussed in this report.

The San Joaquin Experimental Range (SJER) is located near the center of the state in the Sierra Nevada foothills, 45 kilometers north of Fresno at an elevation of about 360 meters. The specific study site within the SJER was located in the natural area, a 32-hectare parcel set aside in 1934 to remain in its natural state and to serve as a check against management treatments applied in other areas of the range.

The 772-hectare Hastings Reservation is located in the Carmel Valley of the central south coast ranges at an elevation of about 525 meters. It was established in 1937 and, except for a 40-hectare horse pasture, has been protected from grazing since that time. The reservation lies some 32 kilometers inland from the coast, at the upper end of the Carmel Valley, between the Santa Lucia Mountains and the Sierra de Salinas Range. The specific sampling sites are all within 1.6 kilometers north-northwest of the headquarters.

Both study sites have a Mediterranean warm summer climate. The mean annual precipitation at the SJER is about 483 millimeters with known extremes from about 229 to more than 813 millimeters. Hastings Reservation's average annual precipitation is about 508 millimeters with known extremes of about 304 to 1051 millimeters. Of the two years of this investigation, 1970-71 was slightly below average at both sites while the 1971-72 season was among the driest since records have been kept (since 1934 at the SJER and 1939 at U.C. Hastings Reservation). Annual precipitation in millimeters for the two years is listed below:

	1970-71	1971-72
SJER	401.3	242.0
Hastings	450.2	304.2

The temperature regimes at the two sites are also similar except that temperatures are slightly more moderate at Hastings Reservation due to its proximity to the ocean. Mean temperatures for the two study sites in degrees centigrade are as follows:

	Mean Minimum		
	Jan.	July	Annual
SJER	0.4	16.0	7.6
Hastings	1.5	10.3	5.2

	Mean Maximum		
	Jan.	July	Annual
SJER	11.8	36.8	23.8
Hastings	15.5	31.8	22.3

Soils at both sampling sites are noncalcic brown soils with a sandy loam texture. The forage samples collected at SJER were on Ahwahnee sandy loam. At the Hastings Reservation sampling was carried out both in Tierra sandy loam and Crafton sandy loam and the results combined. More detailed information on climate, microclimate, soils and specific locations of study sites are available (Holland 1969, 1973).

METHODS

Forage production measurements were conducted at the end of the growing season when plant growth had terminated and the annuals were starting to dry (early May, 1971, and mid-April, 1972). At both sites forage production was measured under three randomly selected, living trees, a dead tree, and in adjacent open grassland. There were no cattle or sheep grazing. Forage was sampled at two meter intervals along transects leading out from the trunks of the trees in east, west, north, and south directions into the open grassland. Herbaceous vegetation was clipped in a 0.1 square meter area at ground level. Clippings were sorted as to species, dried at 105°C for 24 hours, and weighed.

For the dead trees, quadrats within a 6-meter radius of the trunk were considered "under" the tree. This distance was chosen because it appeared from the size of the tree trunk and dead branches that the canopies of these trees had extended for at least this distance. The dead tree at Hastings Reservation had died in 1945. It is not known when the tree at SJER had died, but it is believed that it had been dead for a minimum of 30 years.

In two years, 96 quadrats were clipped under living blue oak trees, and 32 within 6 meters of the trunk of dead trees at both sites. In open grassland 64 plots were sampled at SJER and 76 at Hastings Reservation. All plots from their respective areas were combined and averaged (Tables 1 and 2). Species accounting for 1 percent or more of the total forage production are listed, whereas those contributing less than 1 percent are combined as "other species".

RESULTS AND DISCUSSION

At both SJER and at Hastings Reservation, forage production was significantly higher under both living and dead trees compared to open grassland. At the Hastings Reservation (Table 1), production was about 60 percent higher under living blue oaks and about 80 percent higher "under" the dead tree compared to open grassland. Under living trees, Bromus diandrus, Avena fatua, and Bromus mollis comprised 86.8 percent of the total production. "Under" the dead trees Bromus diandrus, Avena fatua, Erodium botrys, and Hordeum leporinum accounted for 78.8 percent of the total production. In open grassland, *Erodium botrys*, *Bromus mollis*, *Avena fatua*, and *Bromus diandrus* accounted for nearly 80 percent of the total production.

Results obtained at SJER were similar to those of Hastings Reservation (Table 2). Total forage production under living trees was more than 100 percent higher than that of the open grassland. However, total forage production "under" the dead tree, while still about 50 percent greater than that of open grassland, was reduced by 42 percent compared to that under living trees (Table 2). *Bromus diandrus*, *Bromus mollis* and *Bromus arenarius* accounted for over 90 percent of the total production under both living trees and the dead tree. *Bromus diandrus* was the dominant contributing 69-76 percent of the total production. In open grassland *Bromus mollis*, *Erodium botrys*, *Bromus diandrus*, and *Festuca megalura* comprised 84 percent of the total production.

In comparing 1970-71 to 1971-72 (which was a very dry season), it was found that forage production at Hastings Reservation was reduced from an average of 350.9 gms/m^2 in 1971 to 243.6 gms/m^2 in 1972 (a reduction of 30 percent) under blue oak trees. Forage production in open grassland was also reduced by about 30 percent (219 gms/m^2 in 1971 to 152.2 gms/m^2 in 1972). In both years production was over 60 percent higher under blue oak trees compared to open grassland.

At SJER forage production was also reduced in the drier 1971-72 season but only by about 16 percent under trees (407.3 gms/m^2 in 1971, 344.3 gms/m^2 in 1972) and 21 percent in open grassland (209.5 gms/m^2 in 1971, 166.9 gms/m^2 in 1972). In both years forage production was more than 100 percent higher under the trees. No significant changes in species composition were noted in comparing the two years at either of the study sites.

In contrast to previous studies (Murphy and Crampton 1964, Johnson et al. 1959, Murphy and Berry 1973), in which forage production was reported to be less under blue oaks than in open grassland, these data clearly indicate that forage yield is significantly higher under both living and dead blue oak trees when compared to that in open grassland. This higher production, although affected by a complex of environmental factors, seems most significantly a result of more favorable physical and chemical soil properties and a more favorable, moderated soil temperature range (Holland 1969, 1973).

Soil physical properties under blue oak are altered by deposition and decomposition of litter (as well as decay of roots) from both blue oak and herbaceous plants. This gives the soil a higher humus content which results in a more distinct aggregate structure, greater water holding capacity, greater friability, and lower bulk density (Holland 1969). Chemical soil properties are also altered by increased humus in the soil which is a major source of nutrient holding capacity of the soil. As a result, soil under blue oak is higher in nitrogen, phosphorus, magnesium, calcium and potassium as well as having a higher cation exchange capacity and electrical conductivity compared to soils in adjacent open grassland (Holland 1973). All of these soil features, along with the moderated soil temperatures which reduce frost damage in the winter and drying in the late spring, result in a microhabitat more favorable for plant growth and forage production.

Murphy and Crampton (1964) and Johnson et al. (1959) reported that forage production is less under living blue oaks; however, after the trees are killed with 2, 4-D or 2, 4, 5-T, forage yield increased to about twice that of the open grassland. In contrast, the data presented above indicate that forage production is significantly higher under both living and dead blue oak trees. Furthermore, once the tree dies, although there may be a short term increase in forage production, forage yield in the long term gradually decreases. This can be shown clearly by comparing forage production (in gms/m^2) at varying distances (0, 2, 4 and 6 meters) from the trunks of living and dead trees. At SJER the results are as follows:

Distance	Live Tree	Dead Tree	Percent Difference
0m	402.2	422.7	+5.1
2m	371.9	291.3	-27.7
4m	348.8	183.0	-90.6
6m	380.1	164.4	-131.2

Results at Hastings Reservation are similar:

Distance	Live Tree	Dead Tree	Percent Difference
0	176.4	460.5	+263.0
2	362.4	327.0	-10.8
4	350.6	226.9	-54.5
6	319.7	241.4	-32.4

These data indicate that the increased forage yield extends to the edge of the canopy (6 meters) of living trees and then decreases significantly and abruptly outside the canopy in open grassland. Open grassland forage yields averaged 185.7 gms/m^2 at Hastings Reservation and 179.7 gms/m^2 at SJER. By comparison, forage production "under" dead trees was higher than under living trees only next to the trunk and decreased significantly 2 to 6 meters from the trunk. This indicates that the circle of increased forage yield under blue oaks gradually decreases after the tree dies (in this case about 30 years). For example, at both the 4 and 6 meter distances forage production was 32 to 131 percent lower "under" dead trees than under living trees at the same distances. In fact, it was reduced to the point that it was not significantly different from that of the less productive open grassland (Tables 1 and 2).

Species	Live Trees		Open Grassland		Dead Tree	
	gms/m^2	pct.	gms/m^2	pct.	gms/m^2	pct.
Avena barbata	4.6	1.5	3.0	1.6	3.9	1.2
Avena fatua	40.0	13.5	21.8	11.7	45.6	13.6
Amsinckia intermedia	2.9	1.0	0.1	0.1	8.1	2.4
Bromus arenarius	5.3	1.8	2.5	1.3	6.4	1.9
Bromus diandrus	192.1	64.6	17.4	9.4	53.0	45.5
Bromus mollis	25.9	8.7	32.5	17.5	20.3	6.0
Erodium botrys	3.9	1.3	69.1	37.2	43.3	12.7
Festuca megalura	1.5	0.5	11.0	5.9	0.3	0.1
Galium aparine	1.3	0.4	0.2	0.2	2.0	0.6
Hordeum leporinum	8.5	2.9	0.1	0.1	22.9	6.8
Hypochoeris glabra	0.7	0.2	2.9	1.6	0.8	0.2
Lolium temulentum	3.5	1.2	0.1	0.1	0	0
Rumex acetosella	0.1	<0.1	9.7	5.2	19.2	5.7
Other species	7.9	2.4	15.3	8.1	11.2	3.3
	*				*	
TOTAL	297.2	100.0	185.7	100.0	336.0	100.0

Table 1--Average seasonal yield of forage growing under living and dead blue oak trees compared to that in open grassland on Tierra and Crafton sandy loam, Hastings Reservation (1971, 1972). *Significantly higher than open grassland to 0.05 level, using one-way analysis of variance. (Sample sizes and methods given in text.)

Species	Live Trees		Open Grassland		Dead Tree	
	gms/m^2	pct.	gms/m^2	pct.	gms/m^2	pct.
Amsinckia intermedia	0	0	0	0	12.2	4.6
Bromus arenarius	26.8	7.1	10.2	5.7	11.0	4.1
Bromus diandrus	285.0	75.9	34.4	19.1	183.5	69.2
Bromus mollis	31.2	8.3	57.1	31.8	45.5	17.1
Erodium botrys	13.0	3.5	41.4	23.0	3.6	1.4
Festuca megalura	8.6	2.3	18.2	10.1	2.1	0.8
Hordeum leporinum	3.7	1.0	0	0	2.6	1.0
Hypochoeris glabra	0.5	0.1	6.1	3.4	2.6	1.0
Other species	6.9	1.9	12.3	6.9	2.1	0.8
	*				*	
TOTAL	375.7	100.1	179.7	100.0	265.2	100.0

Table 2--Average seasonal yield of forage growing under living and dead blue oak trees compared to that in open grassland on Ahwahnee sandy loam, San Joaquin Experimental Range (1971, 1972). *Significantly higher than open grassland to 0.05 level, using one-way analysis of variance. (Sample sizes and methods given in text.)

Previous investigators have also suggested that species that occur under blue oak trees are less desirable than those of open grassland and by eliminating blue oak the quality of the forage would improve. My results indicate that even after a tree has been dead for thirty years or more, little change in species composition occurs (Tables 1 and 2). These same results were reported by Murphy and Crampton (1964) who wrote, "There is no clear trend as to whether removal of oak favors desirable forage grasses, soft chess and slender wild oats, nor completely removes the less desirable ripgut and mouse barley". Further, Duncan and Clawson (1979) have found that cattle actually prefer the forage under blue oak to that of the open grassland, indicating that perhaps those species found under trees are desirable. Also, in contrast to previous reports, my data indicate that when compared in terms of dry weight (gms/m^2), desirable forage grasses such as Avena barbata, Avena fatua and Bromus arenarius produced significantly more forage under blue oaks than in open grassland (Tables 1 and 2). It is also of significance that the less desirable Hordeum leporinum had a greater production "under" the dead tree than under living trees at Hastings Reservation (Table 1). A detailed report of the effect of blue oak on forage nutritional quality is presented by Holland and Morton (1979).

CONCLUSION

Data presented in this report indicate that the current practice of eliminating blue oak to increase rangeland forage production is not a beneficial management practice in the central California foothills. Forage production under blue oaks is significantly higher than that of adjacent open grassland. In addition, annual range plants start growing earlier and continue to grow longer at the end of the forage season under blue oaks. These characteristics, along with the increased nutrient content of the forage (Holland and Morton 1979), indicate that not only should the existing blue oaks be preserved, but a management plan should be implemented to assure successful future reproduction of blue oaks on rangelands to maintain the long term beneficial effects of blue oak on rangeland production. Without such a program, there will be a gradual decline in rangeland production, in rangeland soil fertility, and in an essential wildlife habitat, all of which will create serious management problems for future generations.

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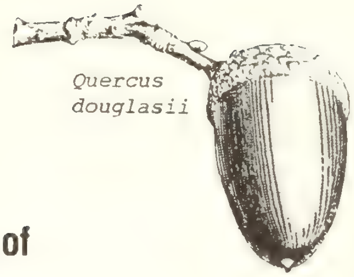

Effect of Blue Oak on Nutritional Quality of Rangeland Forage in Central California[1]

V. L. Holland and Jimmy Morton[2]

Abstract: Forage quality in open grassland and under blue oak trees (Quercus douglasii H. & A.) in central California foothills were compared. The results show that herbaceous plants growing under blue oak trees yield significantly higher levels of total nitrogen, crude protein, phosphorus, potassium and biomass. After the trees die, forage nutrient levels decline to levels found in adjacent, open grassland. The data indicate that removal of blue oaks to "improve rangeland" may lead to long-term decreases in both nutritional quality and yield of foothill rangeland forage.

INTRODUCTION

Removal of blue oak (Quercus douglasii H. & A.) and conversion to open grassland has been advocated as a method of increasing quality and quantity of forage for livestock in foothill rangelands of California (Johnson et al. 1959, Murphy and Crampton 1964, Murphy and Berry 1973). These investigators, working in northern California, have reported that forage production is lower under blue oaks than in open grassland and that cattle prefer forage of open grassland to that under blue oaks. Further, they report that after trees are killed with 2, 4-D, forage yields under treated trees increase to levels higher than those of open grassland. These same investigators report increased palatability and desirability of forage under 2, 4-D treated trees just three weeks after treatment. The reasons for this increased palatability and desirability of the forage are not clear. There was little change in species composition and no significant differences in nutritional quality of the forage under trees treated with 2, 4-D compared to forage under living trees (Johnson et al. 1959, and Crampton and Murphy 1964).

In contrast, Holland (1973, 1979) and Duncan and Clawson (1979), working in central California, found forage production to be 15 to over 100 percent higher under living blue oaks than in open grassland. Herbaceous plants under blue oaks started growing earlier, continued to grow longer at the end of the growing season, and remained green after the grasses and forbs in the adjacent, open grassland had completely dried. Further, Duncan and Clawson (1979) reported that cattle prefer the forage under blue oaks to that of open grassland, even in the summer when forage in both areas is dry. Holland (1973, 1979) found that death or removal of blue oak trees results in a gradual decline in forage production. This decline led to forage levels comparable to those of the less productive open grassland.

This study was initiated for three purposes: (1) to further examine the contradictory reports on the effect of blue oaks on quality and quantity of foothill rangeland forage, (2) to examine the nutritional quality of forage under blue oak compared to that of open grassland, and (3) to determine changes in nutritional quality of forage following tree death.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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METHODS

The study site selected was at U.C. Hastings Reservation (Monterey County), the same as that used by Holland (1973, 1979). Forage from under three of the four trees studied previously, including the dead tree (which died in 1945), were used in this study. The sites in the open grassland were also the same. This was done so that the species composition reported by Holland (1973, 1979) could be used and compared to the forage nutritional quality findings in this study. All forage samples were collected on Tierra sand loam. More detailed information regarding soils, climate, species composition, and site location is available (Holland 1973).

Samples were collected toward the end of the growing season (April, 1974) when plant growth had nearly terminated. Herbaceous vegetation was clipped in 0.1 square meter areas at ground level along a transect that extended out from the base of each tree to the open grassland. For the living trees, forage was sampled at 2-meter intervals. For the dead tree, 1-meter intervals were used. This resulted in a total of nine samples from under living trees, eight from the open grassland and six within five meters of the trunk of the dead tree, which was considered "under" the tree. The canopy of the dead tree appeared to have at least a 5-meter radius when it was living.

Each bulk plant sample was dried at 60°C for one week and then weighed to the nearest 0.01 gram. The samples were then ground to a fine powder and percentages of total ash, nitrogen, crude protein, calcium, phosphorus, and potassium were measured. Ashing was done in a Blue-M Lab-Heat Muffle Furnace. Nitrogen was determined using the boric acid modification of the Kjeldahl procedure (Anon. 1955). Crude protein was calculated using the same method as Johnson et al. (1959). Calcium and phosphorus concentrations were determined using a Norelco SP 90 atomic absorption spectrophotometer. Colorimetry was used to determine the phosphorus concentration. Methods used are based on those of Berry and Johnson (1966), Humphries (1956), and Johnson and Ulrich (1959) and are described in detail by Morton (1974). All data were analyzed statistically using one-way analysis of variance.

RESULTS AND DISCUSSION

Results indicate that forage growing under living or dead blue oak trees differs in several ways from forage growing in open grassland (Table 1). Forage production was significantly higher under the tested trees than in open grassland. Only percent ash and calcium content (both percentage and total uptake) yielded comparable results under the trees and in open grassland. Percent total nitrogen and percent crude protein yielded similar results under the dead tree and open grassland, but much higher values under the living trees. Total uptake (gms/m^2) of total nitrogen, crude protein, and both percent and total uptake of potassium and phosphorus were all higher under living and dead trees than in the surrounding grassland.

These data indicate that the forage production under blue oak trees is not only higher than in open grassland but is also nutritionally superior. Similar results were obtained in a recent study at the U.C. Sierra Foothill Range Field Station (Kay and Leonard 1979). These investigators found forage under living blue oak trees was higher in percent nitrogen, phosphorus and sulfur than that of open grassland or "under" trees killed with 2, 4-D. However, because they report lower forage yields under living blue oak trees, total nutrient uptake in the forage (gms/m^2) was lower than that of open grassland or "under" dead trees. In contrast, our data show that nutrients were higher both in percentage and uptake because of the higher yield under living trees.

Data presented in this study indicate that nutrient levels in the forage decline following tree death. Note that percent nitrogen and crude protein were lower in forage from "under" the dead tree than in that under the living trees but were not significantly different from the levels of open grassland. Both nutrients were significantly higher in forage under living trees. Potassium and phosphorus also show declines "under" the dead tree (Table 1).

Further evidence of decline in forage nutrient content following tree death can be seen by comparing nutrient uptake at various distances from the trunks of living trees and the dead tree. These data (Table 2) indicate that average nutrient content of forage within two meters of dead and living tree trunks, although higher next to the trunk of the dead tree, are comparable. However, at distances greater than two meters from the trunk, nutrient levels in forage "under" the dead tree decrease abruptly to levels comparable to open grassland. In contrast, the higher nutrient content of forage under living trees remains consistently high to the edge of the canopy (6 meters) before declining abruptly into open grassland. Forage growing more than 2 meters from the trunk of living trees but still under the canopy is more than twice as high in nitrogen, crude protein, phosphorus and potassium as that growing at comparable distances "under" the dead tree (Table 2). In fact, forage samples collected 4 and 5 meters from the dead tree trunk are about the same in nutrient content as those of open grassland. This indicates that the circle of increased nutrient uptake in forage under blue oak trees gradually decreases after the tree dies (in this case the tree has been dead for about 30 years).

Table 1. Mean total yield, nitrogen, crude protein, calcium, potassium and phosphorus of forage growing under living oak trees, a dead tree (within 5 meters of the trunk) and grassland at U.C. Hastings Reservation, Monterey County, California.

	LIVE TREES		DEAD TREE		OPEN GRASSLAND	
	gms/m^2	%	gms/m^2	%	gms/m^2	%
Yield	184.1[1]	-	199.8[1]	-	118.5	-
Ash	17.4[1]	9.7[2]	20.0[1]	10.5[2]	12.7	10.7
Nitrogen	3.05[1]	1.68[1]	2.91[1]	1.34[2]	1.30	1.07
Crude Protein	19.04[1]	10.53[1]	18.20[1]	8.38[2]	8.13	6.70
Calcium	0.98[2]	0.55[2]	1.32[2]	0.71[2]	1.11	0.89
Potassium	3.45[1]	1.79[1]	3.07[1]	1.40[1]	1.22	0.92
Phosphorus	0.43[1]	0.24[1]	0.39[1]	0.18[1]	0.19	0.14

[1] Significantly higher than open grassland (0.05 level).
[2] Not significantly different than open grassland.

Table 2. Mean dry weight of total nitrogen, crude protein, phosphorus and potassium in gms/m^2 found in forage at varying distances from the trunk of living and dead trees. The six-meter distance was under the tree canopy. Beyond six meters was open grassland.

	NITROGEN		CRUDE PROTEIN		PHOSPHORUS		POTASSIUM	
Distance (Meters)	Live Trees	Dead Tree	Live Trees	Dead Tree	Live Trees	Dead Tree	Live Trees	Dead Tree
0	3.57	4.23	22.30	26.46	0.47	0.65	3.67	5.13
2	2.90	2.82	18.10	17.64	0.47	0.48	3.84	3.24
4	3.24	1.50	20.30	9.38	0.46	0.18	3.10	1.35
5	-	1.33	-	8.29	-	0.15	-	1.26
6	2.88	-	17.99	-	0.41	-	3.56	-
>6	1.30		8.13		0.19		1.22	

The higher yield and nutrient content of forage under blue oak is in response to a complex of microhabitat conditions created by the trees. However, the most important feature involved is probably the increased level of soil nutrients under trees (Holland 1973). Nutrient uptake by plants is largely a function of soil nutrients. As soil nutrient levels increase, so do the percentages of nutrients in the plant tissue, and consequently the total uptake by the plants. Bentley et al. (1958), in a study conducted at the San Joaquin Experimental Range, reported that herbaceous plants growing in plots fertilized with a mixture of superphosphate and sulfur were higher in crude protein, calcium, and phosphorus than those growing in unfertilized plots.

Blue oak trees accumulate nutrients from deep in the soil and redistribute them on the surface largely beneath the canopy, primarily through litter fall (although leaching of nutrients through rainwater drip and stemflow may be important). Litter from the trees (as well as the herbaceous plants) falls to the soil surface, is mixed into the mineral soil via animal activity, decomposes and releases nutrients into the soil. This results in a higher level of nutrients (including nitrogen, phosphorus, and potassium), organic matter, and cation exchange capacity in soil under trees compared to open grassland (Holland 1973). Because soil nutrients are more readily available under trees, forage production and forage nutrient uptake are higher than those of open grassland. Other factors such as greater soil water holding capacity, moderated soil temperature and more favorable physical soil features under blue oaks also play a role (Holland 1969, 1979).

After the tree dies, the reservoir of nutrients created by blue oaks can apparently be maintained for several years by the decay of the dead tree and the nutrient cycles of the herbaceous plants which are higher in biomass and nutrients than those of open grassland. Nutrient content gradually decreases as the nutrients from the dead tree are released and utilized by the forage. The loss of continuous nutrient input from living trees results in a decline of the nutrient content in the soil and forage, and a loss in herbaceous production. Eventually this area will decline to levels comparable to the less productive open grassland.

In summary, forage under blue oaks has a higher productivity and is higher in nutrients than that of open grassland. Following tree death, nutrient content in the forage decreases and eventually reaches levels comparable to open grassland. This indicates that removal of blue oaks to improve rangeland forage is not a beneficial practice in the foothills of central California. Blue oaks improve quality and quantity of rangeland forage for livestock and wildlife. In addition, they provide needed shade (Duncan and Clawson 1979), moderate soil and air temperatures (Holland 1969), improve rangeland soils (Holland 1973), and provide essential wildlife habitat (Graves 1977, Shields and Duncan 1966, Schitoskey and Woodmansee 1978). Therefore, continued removal of blue oaks from foothill rangelands will have many detrimental effects. If the overall integrity of the foothill woodland ecosystem is to be maintained, programs to properly manage blue oaks must be implemented.

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Quercus douglasii

Effect of Blue Oak Removal on Herbaceous Forage Production in the North Sierra Foothills[1]

Burgess L. Kay and O. A. Leonard[2]

ABSTRACT: Herbaceous forage production beneath blue oak trees increased when the trees were killed. Forage yields were greater in 11 years of the 13 years following treatment, averaging 66 percent if the roots were killed and 45 percent if only the tops were killed. Percent increases were greatest in the driest years. Yields when trees and roots were killed > tops only removed > naturally occurring grassland > under live trees. When trees were killed the botanical composition improved and total ground cover increased. Uptake/acre of nitrogen, phosphorus, and sulfur increased. Bulk density of soil increased. Possible reasons for the changes are discussed.

INTRODUCTION

Studies in northern California have demonstrated that herbaceous forage production can be increased at least fourfold by removing the overstory of blue oak trees (Quercus douglasii H. & A.) (Johnson et al. 1959; Murphy and Crampton 1964). The improved forage yields have been shown to exceed those of adjacent grasslands (Murphy and Crampton 1964). The increases are explained as resulting from the improved availability of light, moisture, heat, and soil nutrients. Also suggested as increasing yields was the stimulatory effect of low concentrations of 2,4-D exuded from the tops of dying trees killed by the cut-surface method (Leonard et al. 1965). Recorded changes in species composition following tree removal were listed as improving forage quality (Murphy and Crampton 1964).

This progress report presents the first 14 years of measurements following tree removal.

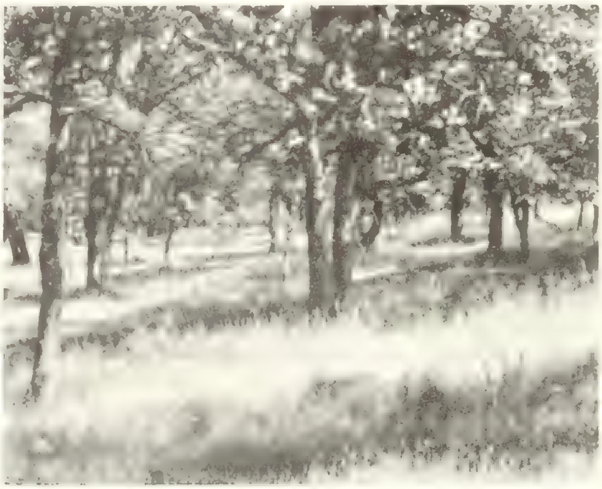

Figure 1--Experimental area before trees were treated. Photographed May 15, 1964, at the peak of the herbaceous growing season.

PROCEDURE

The site chosen is a gentle north slope at the UC Sierra Foothill Range Field Station, at an elevation of 1,750 ft. on the east side of the Sacramento Valley. Annual rainfall during the study averaged 27 inches and varied from 10 to 42 (table 1). Soil is mapped as an Auburn, Las Posas, Sobrante complex. All are red soils derived from greenstone with a clay-loam surface. Depth varies from shallow to moderate with some soils underlain by clay. All have stones independent of the green-stone parent material.

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[1] Presented at the Symposium on the Ecology Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Specialist in Range Science and Botanist (deceased). Department of Agronomy and Range Science, University of California Davis.

The 4-acre study area was fenced to exclude deer, sheep, and cows. All trees were mapped and measured for stem diameter and canopy size. Calibration measurements of forage were made in May of 1963, seven months before the tree-removal treatments were applied, to determine a logical sample size and experimental design. Forage yield was measured beneath 92 trees at the end of this growing season. Six hundred and eighty one-foot-square samples were clipped to ground level and oven-dried. Samples were taken from transects on both the north and south sides of each tree at 1.5 ft from the stem and every 3 ft to the edge of the canopy. Two to seven samples (mean of three) were taken on each transect, with two to four accounting for 88% of the transects. After the calibration period the study area was divided into four replications of about one acre each, and the three treatments and two controls (A-E listed below) were applied to blocks within each replication. Each treatment or control consisted of at least 10 trees to be included as transects in the yield sampling plus all other trees within the one-fourth acre, so as to reduce the edge effect of the observations. In addition to the live trees (untreated areas left as a control) (A) and naturally occurring openings or grasslands (B) which were generally less than 1000 ft^2 and may or may not be influenced by the trees, there were three treatments applied in December 1964: sprouting stumps (C) trees sawed about 6 inches aboveground and removed; trees sawed and removed and the stump painted with 2,4-D amine to prevent sprouting (D); and cut surface treatment (E) in which 2,4-D amine was placed in continuous horizontal cuts which penetrated the cambium layer (Leonard 1956). The trees in (E) fell after rotting in three to five years and were removed from the site.

Green-forage samples were taken near the end of each growing season for all years. The earliest harvest was on April 22, 1970, and the latest on June 2, 1975. Sampling after the calibration year was from a permanent transect on the north side of each of 10 trees or stumps in each treatment of each replication. Square ft samples were taken 1.5 ft from the stem and every 3 ft thereafter to the edge of the canopy. The number of ft^2 samples averaged 33/treatment, for a total of 533, plus 50 samples (10 or more/replication) used to sample the grasslands (B). The samples were oven-dried before weighing.

To determine whether significant phosphorus was released by the decomposition of roots and litter, soil phosphate phosphorus was sampled in the top six inches of treated and untreated areas both 13 and 16 months after the treatments were applied. The bulk density of the soil was sampled 14 years after treatment.

Forage composition and ground cover were measured by the step-point method and combined to obtain ground cover by species (Evans and Love 1957). Forty points were taken in each treatment of each replication on transects within the treatment. Measurements began in the calibration year (1964) and continued through 1974.

Residues of 2,4-D were recovered from the roots in the zone 1-2 ft from the stem 172 days after treatment by digging a stump from treatments A, C, D, and E. 2,4-D amounts were determined by the cotton bioassay method (Leonard et al. 1962) and compared with the amount of 2,4-D in rainfall previously collected beneath cut-surface-treated trees (Leonard et al. 1965).

Recognizing that the herbaceous cover of annual plants would die each season, and the accumulation of residue represents an unnatural condition, efforts were made to remove the current season's growth after it had matured and the seed shattered. In the summer of 1966 the study area was pastured by cows, and in 1970 through 1973 by sheep. Animals were in the area for only a 30-day period in the early summer. Utilization of this dry forage was unreliable and so was discontinued. In the years 1974 and later the general area of the transect was mowed and the forage removed in September, ensuring that an adequate seed source remained.

Data were analyzed by analysis of variance each year for forage yield, species and chemical composition, uptake of N, P, and S, and soil bulk density. Mean data for all years were compared by a split-plot analysis with years as the main plots.

RESULTS

Calibration

Mapping the area showed there were 150 trees/acre averaging 11.1 inches in diameter measured 24 inches aboveground. The diameters varied from 4 to 36 inches, with only one tree/acre exceeding 22 inches. There were no trees smaller than four inches. Canopy radius averaged 9.2 ft on the south side of the trees, and 7.4 ft. on the north, with the radius on the south side being equal to or greater than that on the north for 78% of the trees.

Forage samplings showed no difference in yield between the north and south sides or between samples closest to the stem and farthest from the stem. Therefore all future transects were located only on the north side of the trees. Average yield was 1,480 lb/acre.

Forage Yield

Tree-removal treatments were applied early in the growing season (December 1964) and did not result in significant changes in forage yield in the following spring (1965). Forage yield was 1,420 lb/acre) under live trees (A) and 1,720 lb/acre on grasslands (B). Forage yields for all subsequent years appear in Table 1.

Yields were significantly increased in the first full growing season following treatment (1966), from 960 lb under the live trees (A) to 2,170 lb under the cut-surface-treated trees (E). This 126% increase in forage exceeded the grassland yield (B) and was slightly higher than the stump treatments (C or D), which appeared to be depressed by sawdust accumulated from tree removal. This depression lasted for only one year.

Yield increases were significant in 11 of the 13 years following treatment, averaging 67% for the cut surface treatment (F), 65% for stumps plus 2,4-D (D), and 45% for the sprouting stump (C). The grasslands (B) averaged 21% more than under the live trees (A). Relative yields were A < B < C < D or E (significant at the 0.01 level). Mean yields of D and E are not different.

The relative yield difference between live trees (A) and all tree-removal treatments (C-E) was greatest in the driest year, 1977, when rainfall was 63% below average. This indicates the importance of competition between trees and herbaceous forage for available moisture. Variation in yields between years was nearly twice as great under live trees (A) as on the cut-surface treatment (E). Variation was from a minimum of 390 lb/acre, in 1977, to a maximum of 2,170 lb, in 1971, for the live-tree area (A), and 1,040 and 3,230 for the cut-surface treatment (E) in those same years. This is a 5.6-fold variation under the live trees (A), compared with a 3.1-fold variation on the cut-surface treatment (E) and 4.2 on the grassland area (B). Although the difference in yield between years was highly significant, there was no significant interaction between years and treatments.

Botanical Composition

Total ground cover (all species) for the 10-year period was greater on all cleared treatments (B-E) than the live trees (A), with the newly cleared areas (C-E) greater than the natural openings (B), which, in turn, averaged greater than the live-tree area (A) (table 2). Because

Table 1. Effect of tree treatments on forage yields for the 13 years following treatment. Precipitation data are shown at bottom of table

	Year													
	66	67	68	69	70	71	72	73	74	75	76	77	78	Mean ± S.E.
	Tens of pounds/acre													
A Live trees	96	138	96	176	113	218	140	203	191	130	115	39	190	142 ± 14
B Grassland	158	229	173	236	144	254	128	209	204	168	139	60	184	172 ± 14
C Sprouting stumps	185	222	154	248	178	314	225	214	263	213	165	77	229	230 ± 16
D Stumps + 2,4-D	195	232	186	290	203	352	255	247	296	259	206	91	246	235 ± 18
E Cut-surface	214	224	205	335	195	324	226	240	299	247	202	104	264	237 ± 17
LSD .05	29	58	37	55	47	72	49	NS	52	64	37	32	NS	14
.01	41	--	52	77	65	102	69	--	73	90	52	46	--	19
Precipitation (in.)	21	38	22	42	31	29	18	40	41	24	13	10	34	27

Clemson University Library

Table 2--Mean percent ground cover by species groups and total cover for period 1965-1974

	Grass	Legume	Other	Total
	Percent			
A Live trees	22	4	9	35
B Grassland	27	4	12	43
C Sprouting stumps	31	6	15	52
D Stumps + 2,4-D	32	5	15	52
E Cut-surface	32	16	15	53
LSD 0.05	5	NS	4	6
0.01	7	NS	5	8

of the sawdust the ground cover was lower around trees removed by sawing (C and D) than on the grassland (B) (1965) and the cut-surface (E) (1965 and 1966). In the cut-surface treatment (E) the trees were removed as they fell in later years, so there was never a reduction in ground cover.

Grass cover (1965-1974) was greater on all clearing treatments (B-E) (average 32% cover) than on the live tree area (A) (22%). Most of the increase was in soft chess (Bromus mollis L.), with a small increase in ripgut brome (B. diandrus Roth.).

Legumes (mostly Trifolium sp.), a small component of the ground cover, were not changed significantly by tree removal (C-E). Other forbs were increased slightly. There was an increase in tarweed (Madia gracilis Keck.) and a reduction in geranium (Geranium molle L.).

The difference between years in ground cover (total, grass, legume, and forbs) was

Table 3. Percent nitrogen (N), phosphorus (P), and sulfur (S) in forage, and total uptake of these elements/acre 1966-1978[1]

	N	Total P	PO_4 P	Sulfate S
	Percent in forage			
A Live trees	1.54	.273	.186	.132
B Grassland	1.34	.235	.148	.122
C Sprouting stumps	1.37	.247	.160	.117
D Stumps + 2,4-D	1.33	.222	.145	.116
E Cut-surface	1.34	.221	.138	.120
LSD 0.05	.04	.016	.016	.007
0.01	.06	--	.022	.009
	Average uptake (lb/acre/year)			
A Live trees	21.3	3.9	2.4	1.91
B Grassland	24.9	4.0	2.5	2.28
C Sprouting stumps	27.5	5.4	3.3	2.50
D Stumps + 2,4-D	29.5	5.3	3.1	2.65
E Cut-surface	30.4	5.2	2.9	3.00
LSD 0.05	4.8	0.7	0.7	0.45
0.01	6.4	0.9	0.9	0.60

[1] Except PO_4P, which is for 1967-1977 only.

highly significant (0.01 level), as was the interaction between years and treatments.

Chemical Composition

Percent in the forage of nitrogen, phosphorus (total and phosphate), and sulfur was greatest beneath live trees (A) (table 3). There was generally a maturity difference between open (B-E) and shade-grown plants at the time of harvest, which would account for the difference.

Total uptake/acre of all elements measured was significantly increased by all tree removal treatments (C-E), but did not differ between live trees (A) and natural openings (B).

There was a highly significant difference between years in percent of all measured elements as well as a significant interaction between years and treatments for the percent nitrogen and sulfur.

Soil Phosphorus

Available phosphorus, extracted from the top 6 inches of soil by 0.5 molar bicarbonate solution at pH 8.5 and expressed as ppm phosphorus in the soil, ranged from 12.6 to 18.0 in January 1966 (13 months after tree removal) and 5.9 to 9.4 in April 1966. There was no significant difference between treatments (A-E) at either date.

Bulk Density of Soil

Measured 14 years after treatment, soil collected from beneath live trees (A) was significantly lower (0.05 level) in density (1.074) than soil from natural openings (B) (1.183) or on cut-surface-treated areas (E) (1.179). Measurements were made near field capacity, and there was no difference in water-holding capacity. The difference was noticeable in walking on the area, with the tree-covered area being relatively spongy.

DISCUSSION AND CONCLUSIONS

Forage yield increases were consistent and long-lasting. Measurements will continue in an effort to determine just how long they will persist. The increases to date are much less than previously reported, however (Johnston et al. 1959; Murphy and Crampton 1964). The trees in this study were larger than those in the above studies (11.1 in., compared with 7.5 and 8.0 in.). The number per acre was intermediate--150, compared with 115 and 225. Herbaceous ground cover under the trees was identical in this and the study by Johnson et al. (1959). Rainfall was intermediate, 27 inches, compared with 20-25 and 37 inches. The elevation was much higher (1,750 ft vs. 500 and 900 ft). The growing season was probably longer in this study because of the higher elevation and north slope. The growing seasons would start at the same time but maturity may be 15-20 days later than at 500-900 ft at this field station.

In determining the potential of a tree-covered area for increased forage production from tree removal it may be best to compare yields under the live trees with open areas. This and other studies in northern California indicate that the increased yield can be expected to equal or exceed yields in the grassland areas. Murphy and Crampton (1964) indicate about a threefold difference between a tree and grassland area before the treatment that gave 400-650% increases when the trees were killed. By comparison, the study reported here shows only a 17% difference between grasslands and tree-covered areas, and a 67% increase from removing trees. Not all areas will indicate increased yields. Holland (1973) found that production under blue oak trees in Madera Co., some 170 miles south of this study area, was 60 to over 100% higher than that of an adjacent open grassland.

Shade (light intensity) cannot be completely ruled out as a factor in reduced forage production beneath trees. However, the shade of the dead trees in the early years after cut-surface treatment (E) did not reduce yields below those from removing the tree and treating the stump (C). Leonard et al. (1965) suggest that the leaves of blue oak do not develop until after most of the herbaceous growth has occurred, thus eliminating shade as a factor.

Competition with the living tree, perhaps for moisture and nutrients, may be a factor, as evidenced by the difference in yield between treated stumps (D) (roots killed) and allowing stumps to sprout (C) (Table 1). Also, production was greater beneath standing dead trees (E in early years) than standing live trees (A).

The increase in yield in excess of grassland areas (B) following tree treatment (C-E) may be due in part to nutrients released by decomposing roots. Forage increases were greater where roots were killed (D or E) than where roots were not killed (C).

Total uptake of nutrients (nitrogen, phosphorus, and sulfur) was greatest in all tree-removal treatments (C-E), possibly indicating greater availability. Soil phosphate measurements apparently were not precise enough to detect increases. However, these samples were only from the top six inches and may have failed to measure the contribution of the tree roots, which are abundant at 8-20 inches (Leonard et al., 1965). The lowest levels of soil phoshorus measured are suggestive of a possible deficiency.

The standing live trees contributed to reduced soil bulk density, and their removal resulted in increased density even with minimal livestock use. Animals were present only a few times, and then only in the dry summer months, so their influence on bulk density should have been minimal.

A stimulatory effect of low concentrations of 2,4-D seems unlikely. Leonard et al. (1965) measured 2,4-D in rainfall under cut-surface-treated trees and found small amounts in the first year after treatment, but none after one year. Roots measured in this study 1-2 ft from the stump contained 0.040 ppm and 0.011 ppm from the cut-surface (E) and 2,4-D-treated stump treatments (D), respectively, measured 172 days after treatment. The 2,4-D may have increased the rate of decomposition and resulting availability of plant nutrients.

The changes in botanical composition following tree removal generally improved forage quality. Of greatest importance was the increase in soft chess. The compositional changes might have been quite different if the area had been grazed in winter and spring, as is the common practice. An increase in legumes and other forbs could be expected if grazed.

The lesser variation between years in forage production on grassland or tree-removal treatments than on tree-covered areas is of great value to a livestock operator. The reduced variation may be of as much value as the increase in total forage production that results from tree removal.

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Quercus douglasii

Oak Trees and Livestock—Management Options[1]

Alfred H. Murphy[2]

Abstract: In California, approximately 10 million acres of woodland-grass type offer opportunities for modification of the tree cover to improve their use in livestock management. Research projects on oak-grasslands at the Hopland Field Station, over the past decade, have provided information for the improvement of quality and quantity of range forage on mixed oak-grass vegetation, impacts of tree removal on water productivity, and the expectation of soil movement on various geologic formations by removal of tree cover.

INTRODUCTION

Most rangeland livestock operations are confronted with the economic fact of obtaining the best returns from grazing lands. While yield and composition of forage is influenced by weather, soil, water, exposure, and plant cover, man can encourage those plants that best meet his production needs. On many acres of California rangelands, oak trees have a major impact on the productivity of the forage system.

Of California's 68 million acres of wildlands, Love (1967) estimates that 10 million acres are in the woodland-grass type; he infers that 10 percent could be improved in value by 12 times, and 50 percent by three times, while the remaining 40 percent would have limited improvement potential. In a grazing study with sheep at the Hopland Field Station, Murphy and Berry (1973) stated that the removal of oak trees increased the value of livestock products by five-fold. In the foothills of the Sacramento Valley, Bell (1960) reported a five-fold increase in dry feed and a four-fold increase in forage protein production per acre where blue oaks were killed by the cut-surface treatment. Plant species composition study under treated oaks by Murphy and Crampton (1964) indicated that the shade-tolerant forb species were eliminated by killing the oaks, while several of the better forage grasses increased. In a watershed conversion study from oaks to herbaceous cover, Pitt (1975) reported both increases and decreases in percentage composition of both desirable and less desirable forage species.

Removal of trees and brush from rangelands significantly influenced the water yield pattern of treated areas. An extensive review of watershed management studies by Burgy and Papazafiriou (1971) revealed a preponderance of evidence and virtually unanimous conclusion that the reduction of vegetation density....will result in increased total water yield. The replacement of deeply rooted plants with shallow-rooted grasses and forbs make greater amounts of water available; Burgy (1967) attributes this to reduced transpiration and smaller interception loss.

The aim of this paper is to point out some of the facts of tree management developed at the Hopland Field Station and their influence on vegetation, livestock, and water. These facts can be useful in decision making for landowners and managers who use the land for livestock production and where oaks are part of the rangeland plant community.

THE HOPLAND FIELD STATION

The Hopland research station of the University of California consists of 5,358 acres

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(2170 ha), located in Mendocino County's central coastal mountains. The greater part of the land area is represented by vegetational types that include oak trees. The woodland-grass type amounts to 36 percent of the area which is characterized by a scattered overstory of blue oaks (*Quercus douglasii* H. & A.), valley oaks (*Q. lobata* Nee), and interior live oaks (*Q. wislizenii* A. DC.), and an understory of grasses and forbs. In contrast, dense woodland covers approximately 22 percent of the Station area and consists of the aforementioned oaks plus black oaks (*Q. kelloggii* Newb.) Oregon oaks (*Q. garryana* Dougl.), and several other oaks of limited abundance. In part of this dense woodland are two prominent hardwoods--madrone (*Arbutus menziesii* Pursh.) and California bay (*Umbellularia californica* H. & A.)--with very little herbaceous vegetation found beneath their dense canopy. Other vegetative areas of the Station include 23 percent in open grass, 15 percent in brush, and the balance of 4 percent in minor categories (Heady 1961).

Climate is characterized as cool, mean temperature 43° F (6.1° C), and wet from November to April, with annual precipitation of about 37 inches (940mm); the balance of the year is usually warm, mean temperature 65.4° F (18.6° C), and dry with limited rainfall.

Soil varies in depth to 6 feet (1.8m), on benches but mostly are 1 to 3 feet (.3 to .9m) on moderate to steep slopes and include 18 different series (Josephine, Laughlin, Los gatos, and Sutherlin are most prevalent), located in an elevation range of 500 (153m) to 3,000 (915m) feet. Generally the soils decrease in depth with increased elevation and this depth often determines the character of the woody plant population (Gowans 1958).

Generally the herbaceous vegetation will yield an average of 2,000 pounds per acre (2240 kg/ha) dry weight (DW) but yearly fluctuations vary from 1,300 to 3,600 pounds per acre (1455 to 4032 kg) DW depending on climatic variable. Most all of the plants making up the herbaceous cover are annual grasses, clovers, and other forbs, with perennial plants having a minor role.

STUDIES AT THE HOPLAND FIELD STATION

For a 20-year period (1958-1978), annual forage yield determinations have been collected from pastures with open ground and under tree canopy. These pastures represent the low to mid-elevation areas, 600 to 1,200 feet (183m to 366m), with soil depth of 1 to 3 feet (.3 to .9m), slopes up to 50 percent, and mostly south to west exposure; yield averages of the open ground were 2,400 pounds per acre (2688 kg/ha) DW, whereas the yields under an oak tree canopy were 1,400 pounds (1568 kg) DW or a reduction of 1,000 pounds (1120 kg) DW due to tree competition. Composition of vegetation in the two types were as follows:

Vegetative Type	Open Ground	Under Tree Canopy
	------percent	cover------
Annual grass	64	53
Forbs	23	36
Legumes	13	7
Perennial grass	--	4

Under the tree canopy such grasses as ripgut (*Bromus rigidus* Roth.) and dogtail (*Cynnsorus echinatus* L.) were dominant; they are considered as poor quality forage plants.

HYDROLOGIC STUDY

Perhaps in terms of major impact on land areas, the hydrologic study of watershed management at the Hopland Field Station gives the most comprehensive view of the effect of tree removal. Over a 25-year period, intensive management studies relating to vegetation, grazing use, soil, and water have been observed.

Two watershed areas--210 and 60 acres (85 and 24 ha)--had water yield, runoff, erosion, forage, and livestock data collected during three testing periods--pre-treatment, treatment, and post-treatment. The pre-treatment period represented the watershed condition before any changes were applied. The treatment period involved reduction of trees and shrubs by cutting, chemical treatment, and fire followed by seeding of grasses and legumes. The final phase was evaluation of treatments by the collection of hydrologic data, sheep grazing use, and forage productio

The conversion process in the 60-acre Watershed I was rapid, by falling the trees, burning the debris, and seeding grasses and clovers during the period of June to Septembe whereas in the 210-acre Watershed II the tree were killed by applying 2,4-D amine by the cu surface method around the tree trunks. Five years after the tree treatment, a summer controlled burn was used to remove dead, woody debris followed by seeding with grasses and legumes.

Forage Production

Sheep were used to measure the effect on forage, with animal unit months (AUM) as the measure of production; before, during, and after the tree treatments. In both watershed treatment methods, the increases were similar before treatment the average grazing capacity was 50 AUM, following conversion from woody cover to herbaceous cover it increased to 300 AUM. The major increase in feed production occurred on areas where tree canopy was dense and little herbaceous cover was present; approximately half of the acreage was classed as dense. The improved forage condition was not only achieved by reduction of tree competition but by substituting grasses and legumes that were capable of producing as well or better than the resident species.

Water Yield

Benefits derived from tree removal also included an increase of water yield either by surface or sub-surface flow. Research by Lewis and Burgy (1964) determined that oak trees will extend roots through fractured rocks to depths in excess of 70 feet (21.4m). In tree covered areas, where the density of trees was 150 to 500 per acre, the removal of trees increased water runoff per year from 2 to 13 inches (5.1 to 33cm) in an eight year period (Burgy and Papazafiriou 1970). The average increase of total runoff attributable to tree removal management was found to be in the order of 50 percent as compared to pretreatment amounts.

Interception losses in shrubs and trees are higher than for grasses and forbs. Also, when plants with deep roots, that remain in leaf during most of the year, are replaced by shallow-rooted plants with short growing season, the reduction of evapotranspiration losses results in an increase in water yield (Burgy and Papazafiriou 1971). This was demonstrated in Watershed II, where an intermittent stream became perennial after vegetative conversion from trees and brush to grasses and forbs. This evapotranspiration reduction resulted in the increase and extention of base flow through the dry season.

Variations in watershed response to tree removal is well illustrated in these two areas. Geophysical drilling revealed that Watershed I had extensive fracturing of rock structure allowing water drainage out of the area by sub-surface flow whereas in Watershed II the clay and rock underlying the surface were impervious, holding water near to the surface. In Watershed II the increase of available water due to tree removal was thus expressed as stream flow. Previous to tree treatment the stream flow ceased by July, whereas following tree treatment the stream was characterized by a perennial flow. In Watershed I, where sub-surface drainage was good, the increase in available water was not expressed as visible stream flow. Increased water flow in Watershed II resulted in greater channel erosion and scouring. The higher soil moisture resulted in many zones of soil saturation causing creep deformation in a number of sites. It was also observed that if the soil was saturated, earth tremor shocks caused liquefaction to occur (Burgy *et al.* 1971). These erosion conditions did not develop in Watershed I after tree removal, as sub-surface water drainage out of the area prevented soil saturation.

CONCLUSIONS

The removal of oak tree cover will modify the rangeland ecology; thus the new conditions must be assessed to determine the value of tree cover modification. In many situations forage quality and quantity will improve, springs and stream flow will increase, and an economic return can be obtained if the tree material is harvested for firewood. If a large percentage of the trees are killed, under some geologic situations, erosion will increase in terms of channel scouring as well as by land slips. The browse value of oaks within reach of grazing animals will be lost and the Fall acorn crops will be reduced. It is important that rangeland operators fully assess the changes that will result from tree removal to determine whether they will benefit his future land use plans.

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Quercus chrysolepis

Energy Yield Potentials of California Oaks and Other Wood Biomass[1]

Al Gronckı [2]

Abstract: California oaks are a significant part of natural biomass stands in California that are capable of producing up to 30 million tons of dry wood per year. Managing the commercial and non-commercial oak stands with consideration of environmental needs could produce positive management benefits with incidental direction of oak biomass into a variety of possible alternative energy production processes.

INTRODUCTION

There is an increasing awareness of the potential various forms of wood biomass hold as a renewable energy resource (Howard 1974, Alich 1976, Howlett 1977). New plants using wood energy for heat, steam, and electricity production are being considered throughout the nation. Research for the conversion of wood to liquid or gaseous fuels is being funded by Federal and State governments and by private industry and educational institutions.

Nationally we produce 1.25 Quads[3] of energy from wood. Preliminary estimates indicate a potential of 8.3[4] Quads of energy from wood. The Forest Service predicts that 5.2 of these Quads will be realized. This will amount to 7% of the Nation's energy needs. Estimates, however, have been made from resource information that was collected for conventional convertible wood products. Information collected for total biomass production may change these estimates.

In California, preliminary estimates based on incomplete data indicate we are producing 30 million dry tons of unused forest biomass each year. We do not know how much of this is recoverable because of unknown harvesting and transportation costs and environmental considerations. Management regimes for California's oaks, as an example, have not been designed, and is one reason for this symposium.

Thirty million tons represent 0.51 Quads or 7.8 percent of California's annual energy budget (Craig, et. al. 1978) of 6.5 Quads (based on 1975 figures).

Where do California oaks fall into this scheme? California hardwoods are expected to yield 3.5 million dry tons of biomass annually, or approximately 11.4% of the total 30 million tons of estimated biomass production. The oaks are a significant part of the hardwood resource. The above figures assume a hardwood culture dedicated to more economically valuable product uses than energy. The 3.5 million tons consists of estimated logging residues from commercial hardwood stands, and managed biomass harvesting from non-commercial stands.

Hopefully this Symposium and other research and inventory work will provide better data in the near future in the following categories:

1. Acreage of commercial oak stands.
2. Acreage of non-commercial oak stands.
3. Delineation by species, volume and size classes by conventional inventory standards and total above-and below-ground biomass standards.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

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[3] 1 Quad = 1 quadrillion BTU's or 1×10^{15} BTU's.

[4] National Framework for Energy from Biomass, U.S. Forest Service, Washington D.C., May 25, 1977, Unpublished draft.

RELATIVE EFFICIENCY OF WOOD AS FUEL

Wood as fuel contains approximately 8,500 BTU's per pound or 17,000,000 per ton. These figures vary somewhat within species because of contained extractives, but generally can be used. Bark is closer to an average of 9,000 BTU's per pound or 18,000,000 per ton.

These figures are for dry wood. Green wood unfortunately contains high percentages of water. Green wood generally contains as much water by weight as solid wood substance. The relative efficiency of wood as a fuel is complicated significantly by the presence of this water. It increases handling and transportation costs, and decreases the efficiency of the combustion process. If used in a green state, roughly 20-30% of the contained BTU's will be used to drive off the water. Air drying and the use of waste stack heat can increase the relative efficiency of combustion. The combustion of dry wood in conventional boilers compares favorably with oil and coal. Because more wood is required for equal heat outputs, there is some increase in storage, handling, and size of combustion equipment required for burning wood.

Dry wood has a boiler efficiency of 80.08% (Curtis, 1978) wood at 15% Moisture Content has an efficiency of 78.08%.

Wood at 30% Moisture Content has an efficiency of 76.08.

Wood at 60% Moisture Content has an efficiency of 72.07%.

Wood at 100% Moisture Content has an efficiency of 66.72%.

Oak is preferred firewood for home consumption because it is dense and therefore contains more BTU's per cubic foot than Ponderosa Pine, although Ponderosa Pine actually contains more BTU's per pound. Since wood is often purchased on a weight basis in industrial operations, pine is a better buy than oak. Since wood is bought on a volume basis for home use, oak is a better buy than pine, although price adjustments are generally made to accommodate these differences in BTU content. Table 1 below illustrates some of these relationships for some of our Western species.

Table 1 - Densities and Heating Values for Some West Coast Species

Species	Density Dry lb./cu. ft.	BTU/lb	Higher Heating Value-Dry BTU/cu.ft.
Douglas Fir	38	8,900	249,000
Ponderosa Pine	24	9,100	218,000
Lodgepole Pine	24	8,600	206,000
Red Alder	23	8,000	184,000
Ore. White Oak	37	8,110	300,000

The use of wood stoves for space heating, cooking,and heating water has increased significantly in the last few years. Firewood permits in California from Forest Service Ranger Stations totaled 78,304 cords in 1972, and 329,634 in 1977, a 420% increase. It is difficult for the homeowner to evaluate the effectiveness of the various wood-burning stoves. Comparative efficiency tests have not yet been published, although some are being conducted by the Department of Mechanical Engineering at Auburn University, Auburn, Alabama.

Without this comparative information, there are three things you should look for in a good stove:

1. It should be air tight.
2. It should provide for secondary combustion of fuel gases.
3. It should provide refractory brick lining.

A good reference is the Woodburners Encyclopedia (Shelton and Shapiro, 1976.) This reference discusses the pros and cons of most of the models presently on the market. It also gives good information on safety, which should be a primary concern of yours if you are going into home wood heating. Consult your local county building inspector for installation specifications, and then follow a rigid maintenance program.

TECHNOLOGY OF INDUSTRIAL WOOD COMBUSTION

The combustion of wood by industry has undergone many changes in recent years. Some modern combustion units are smokeless and operate unattended. A brief review of the various types of systems in use will illustrate the broad range available today.

Dutch Oven

Many old furnaces and some new ones use this system in which the fuel is burned in a pile. The rate and efficiency of combustion is regulated by the design and use of over-and under-fire air. Too much primary air under the fire lowers the combustion temperature and produces more unburned particulates. Not enough over-fire air prevents the secondary combustion of particulates and gases. A properly designed furnace provides the proper amounts of each kind of air, and some means of collecting and burning all particulates.

If particulates are not burned, then they must be collected in precipitators, wet scrubbers, or bag house collectors to meet air pollution standards. These same comments apply to many of the other systems described here.

Moving Grate Systems

There is a wide variety of systems in which the fuel is burned on a grate that moves in some fashion. There are dumping grates, reciprocating grates, and moving grates. The intent is to spread the fire in a uniform manner and to dispose of ash efficiently. There is a wide range of combustion efficiency depending on the design of the furnace and the use made of air to obtain complete combustion.

Suspension Systems

These are systems that use currents of air to suspend the fuel while it is being burned. There are simple suspension systems as well as more complex horizontal or vertical vortex or cyclonic systems. Some use a single combustion chamber and some use secondary chambers for combustion or to trap unburned particles and return them for additional combustion.

Fluidized Beds

These systems employ vertical air flow and a bed of sand or other material to keep fuel in constant agitation or suspension. They can vary greatly in size. The largest units will consume 250 tons of hog fuel per day. Although hogged fuel or chips are desirable, solid wood may also be burned.

Fluidized bed systems, though expensive, have several advantages. They can burn very wet fuels and they are very flexible. They may fire boilers directly, may provide direct heat for heating or drying systems, or may produce gas for turbines or subsequent combustion. A disadvantage is they are very expensive and usually only justified for very large operations.

Pyrolysis

Pyrolysis, or destructive distillation, is the combustion of material with a minimal amount of oxygen. Low-temperature pyrolysis produces gas, charcoal, and pyrolytic oils. High-temperature pyrolysis or gassification produces low BTU gas, mostly carbon monoxide, but some methane and hydrogen also.

The low temperature pyrolysis permits the production of a mixture of char and oil that may be hauled to some other location for combustion. It may be further gassified, mixed with fuel oil for combustion, or processed chemically.

High-temperature pyrolytic gases can not be transported any significant distance. They may be used to operate gas turbines, fire steam boilers, or to operate internal combustion engines, either for shaft horsepower or to run electric generators.

Products of both processes may be used to create other chemicals such as ammonia or methanol.

Chemical Systems

A variety of chemical systems exist to convert wood to methanol, ethanol, furfural, acetic acid, ammonia, oil, crude sugars and animal feeds. Some of these systems are: acid hydrolysis, wet oxidative hydrolysis, fermentation, carboxylase and hydrogassification.

Hybrid Geothermal

This is a system designed to use the vast amounts of low-temperature geothermal fluids found in the Western U.S. in combination with a wood-fired steam system. Geothermal fluids are used to dry hogged wood material and pre-heat boiler feedwater. The boiler feedwater is then super-heated in a wood-fired boiler and used to generate electricity.

Pelletization

A number of pelletizing processes exist. Pellets range in size from animal feed to presto-logs. The pellets may be used in any of the processes described above and in themselves do not constitute a new technology, pelletizing having been used since 1923. They do decrease transportation costs because the wood in pellets must be reduced to about 15% moisture content (dry basis). The increase in density also reduces the size of necessary storage facilities, and provides a transportable product for home fireplaces and campground fires. The experts in this field do not anticipate much use for pelletizing in industrial applications in the future because the advantages are not great enough to justify the expense of pelletizing.

Chemical Derivatives

In addition to destructive distillation processes for converting wood to chemicals, wood and foliage contain a great number of valuable chemical extractives. A quote from J.E. Stone of the Canadian Forest Service illustrates the potential that exists for chemical uses of wood and exemplifies another attitude toward utilizing wood for energy (Carlisle 1976).

"Using a complex organic substance merely for its calorific value is one of its crudest uses . . . It takes no cognisance of the chlorophyll, carotene, vitamins, protein, essential oils, etc. in the foliage. No cognisance of the beautiful fibre structure of wood. No cognisance of the polymeric properties of the cellulose molecule, of the fact that 60 percent or more of the wood is carbohydrate, or that lignin is an aromatic phenolic polymer with many interesting properties . . . It is a treasure house of structural and chemical components which should be exploited to their fullest extent." He further suggests that surplus trees and their components should be put into a process stream in which the highest value components are removed sequentially. Again we come up against the idea that tree components are possibly too good to burn.

EXISTING AND POTENTIAL ANNUAL WOOD BIOMASS SUPPLIES IN CALIFORNIA

The following data on biomass supplies was developed in 1978 as testimony for the California Energy Commission (Table 2). They requested it for consideration in hearings on siting applications for fossil fuel power plants in the State.

This section covers oak as well as all other sources of wood biomass. Although we have been unable to segregate the oak resource from the other categories of commercial and non-commercial hardwoods, the implications of managing the oaks forces us to the same management concerns.

Material Available With Existing Technology

Category 1 - Mill Residues

The Forest Service projects a total primary mill residue of 7.7 million dry tons (Howard 1974). Stanford Research Institute estimates 4.6 million dry tons (Alich 1976). The Mitre Corportion estimated 8.8 million tons (Howlett 1977). The amount of this residue being used fluctuates with the pulp chip market. We presently estimate 3.0 million tons unutilized. With the increased interest in power generation by primary mills, this surplus will soon decrease to about 1.0 million tons.

This mill residue is primary mill residue from sawmill and veneer mills. It does not include residues from secondary processing facilities such as molding plants, sash and door plants, cabinet and furniture plants and miscellaneous forest industries. Secondary mill residue is reported as a portion of urban wood residue.

A number of sawmills in California are cutting some oak. Cal-Oak in Oroville cuts oak almost exclusively, and they are on this program to talk about their operation. Kimberly Clark, Philo Timber Co., Simonson Timber Co., Schmidbauer Timber Inc. all cut some incidental hardwoods including some of the oaks.

Humboldt County and at least one Company are actively studying the establishment of a hardwood processing plant in Humboldt County.

Category 2 - Woods Residue

The Pacific Northwest Forest and Range Experiment Station has published voluminous data on the volumes of logging slash (Howard 1973), (Adams 1976) & (Grantham 1974). Data has not been developed, however, to predict annual accumulations of logging slash on a statewide basis. SRI estimated 5.1 million tons per year; the Mitre Corporation estimated 4.3 million tons per year. We believe both of these are low and estimate 6.5 million tons based on the following assumptions:

A. 5 billion bd. ft. harvested in an average year.
B. 30 thousand bd. ft. per average acre of harvest.
C. 159,000 acres harvested each year on an assumed clear cut basis.
D. An average residue volume of 40 tons per acre. A significant portion of this logging slash is from understory hardwoods.

Woods residue is any material from the severed tree (excluding the stump) that is not harvested or removed from the site. Woods residue is often categorized by size classes. The minimum diameter size of material most often used in computing woods residue is 4 inches. This for two reasons: (1) the diseconomy of handling smaller material; (2) the need to leave smaller material to maintain nutrient balances.

As stumpage prices increase, utilization standards will become more exact and less residue will be left in the woods. We estimate a decrease of 7% due to increased utilization standards in the woods in the long term. Virtually none of this material is being used now except for firewood and incidental salvage by small portable sawmills. In the long term, most of this material, down to a 4" diameter, will be utilized for energy, particle board, or pulp.

Category 3 - Conifer Thinnings

Fuel loading data from conifer thinnings indicate a range from 7 tons to 48 tons per acre (Maxwell 1976). Using an average of 20 tons per acre, we arrive at a total of 6.3 million tons per year available, assuming thinning 2% of the 15,863,000 acres of softwoods each year. This material is available short and long term. The pulpwood industry in California has never utilized roundwood supplies, and additional pulpwood capacity in California is not anticipated due to environmental constraints. Most of this material is therefore assumed to be available for energy purposes. This data applies to pre-commercial thinning material only. Commercial thinning residue is aggregated with other forms of logging slash.

Category 4 - Dead and Dying

Endemic mortality during an average year approaches 1 billion board feet in California. About 13% of this material has been utilized in the past. Current Forest Service efforts to increase utilization of this material will reduce availability in the long run. Forest Service and State of California policy to retain certain levels of dead trees for cavity-nesting birds and animals will further reduce the long-term availability.

During epidemic insect outbreaks, such as the present one augmented by the drought of 1975-77, vastly increased amounts of dead and dying material are available. An estimated 24 million tons is presently available. Much of this will, however, be used for sawlogs due to the increased Forest Service and industry effort to salvage as much of this material as possible.

In the long term, this amount should decrease as virgin old-growth stands disappear and thinning regimes increase the vigor of young stands. No estimates have been made of volumes of dead and dying hardwoods, though a recent survey on the Six Rivers National Forest[5/] indicates that 75 percent of a total volume of 1,130 MMBF of California Black oak is either dead or live cull.

Category 5 - Urban Residue

Urban residues represent a virtually untapped source of wood fiber. Collection costs have been absorbed and dumping costs add a negative value that is readily recovered. Cities are generators of wood residue as much as forests are. Represented in urban residues are the following categories of material:

Secondary Mill Residues
Demolition Waste
Construction Waste
Crating
Tree Maintenance & Removal
Building Construction

[5/] Six Rivers Timber Harvest Scheduling study, 1979, unpublished.

Household waste is not considered. Only those wastes delivered in separate, distinct loads to dumps were considered. The data we have comes from the Kelbro Corporation[6] which has produced 180,000 tons per year from an area bounded roughly by Sacramento, Yolo, and Placer Counties. These three counties contain 4.2% of the California metropolitan population. An extrapolation to the total metropolitan population in California produces an annual figure of 4.3 million dry tons per year. Much of the residue in this category is hardwood, especially pallets, secondary mill waste, and city tree maintenance material.

Category 6 - Orchard Prunings

Orchard prunings are a readily available resource with negative value. The California Department of Agriculture estimated 2.0 million tons available each year. Some people wish to categorize them with agricultural residues, but they have the same combustion attributes as other wood residues.

Some agricultural companies are already considering using their prunings as a source of fuel for their drying operations, so some of these will disappear in the long term.

Category 7 - Commercial Hardwoods

We assume a developing industry utilizing the commercial hardwood stands in California. Species include Oregon White Oak, Calif. Black Oak, Alder, Big Leaf Maple, Cottonwood, Sycamore, Calif, Laurel, Calif. Valley or White Oak, Tanoak, Chinquapin and Madrone. Our hardwood resources are too valuable to use exclusively as a wood energy resource. Volumes of slash from commercial hardwood stands vary from 50-120 tons per acre based on fuel loading studies done at PNW (Maxwell 1976).

Inventory data on commercial hardwoods has been lacking, because the hardwoods have previously not been important. Recent inventory work on the Six Rivers National Forest[5] reports 2.3 billion board feet of live, sound, hardwoods, 1.1 billion of which is Tanoak and 331 million board feet of which is Black and White Oak. They report another 2.2 billion board feet of dead or live cull, all of which would be available for energy purposes.

Extrapolation of this data to the three counties of Mendocino, Humboldt and Del Norte counties results in 16-20 billion board feet of hardwoods in just those three counties. Since the better hardwood sites occur on the private commercial forest land, these figures are probably conservative. Also, early harvesting on the private commercial acreage without regeneration and stand improvement practices has resulted in heavy regrowth to hardwoods.

Category 8 - Noncommercial Hardwoods

Fuel loading studies of material in this category conducted on the National Forests[7] indicate a range from 40 tons to 110 tons per acre occurs in natural stands. We have used a low average loading of 50 tons per acre and a rotation of 40 years. Culmininination of mean annual increment of biomass will occur much sooner, somewhere near ten years. We have chosen the longer rotation due to unknown factors of nutrient cycling and reproductive potential to be discussed under Environmental Constraints.

Total biomass available on an annual basis under this regime would be 1.6 million dry tons. A published report that supports these figures was done for the central coast hardwoods (Pillsbury, 1978).

Category 9 - Noncommercial Softwoods

The 7.5 million acres of noncommercial softwoods is represented by such species as juniper, pinon pine, digger pine, and very poor stands of the commercial species such as Ponderosa pine and Douglas fir. By definition, noncommercial softwood stands are stands that are growing less than 20 cubic feet per acre per year. An average growth would probably be closer to ten cubic feet per acre per year. These figures are, of course, based on sawboard inventory standards and not on biomass standards. Assuming, however, that we will not be using whole tree harvesting because of nutrient cycling constraints, we have used a figure of 10 cubic feet per acre per year. While this results in 1 million tons of biomass per year, we feel the need to proceed cautiously in this type as so little is known of the possible consequences of harvest regimes in low-volume, sensitive stands. Harvesting in the pinon juniper type will probably occur to augment the grazing resource.

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[6] Unpublished data from KELBRO Corporation, Sacramento, CA.

[7] Unpublished data. Fuel loading studies on individual National Forests in Region 5.

Category 10 - Chaparral

Fuel loading studies by the Riverside Fire Laboratory[8] indicate a range from 10-46 tons per acre. They also estimate 20 years for a burned-over site to reach optimum loading again. We have used an average of 20 tons per acre and an assumed rotation of 20 years. These assumptions produce an annual production of 7.6 million dry tons per year.

Since harvesting technology has not been developed for chaparral, no estimate has been made of the percentage of this material that will eventually be available.

The figures for all categories project annual total biomass production. Physical, economic, or environmental availability are not considered, nor is the backlog of residue from previous logging and milling activities considered.

MANAGEMENT EFFECTS OF HARVESTING FOR BIOMASS

Managing the forest resource for biomass production as well as higher valued products will involve the areas of fire control, insect and disease management, stand improvement, wildlife management, range, and esthetics.

Fire Control

Substantial resource losses have occurred in California because of wildfire in commercial timber stands. Suppression of these fires has been aggravated by accumulations of slash in timber harvested areas. More complete utilization for energy or other products will help reduce these losses and will also reduce fire suppression costs.

From a fire management standpoint, the use of slash, dead and dying trees, and thinning waste for fuel can only be beneficial. Backlog slash from inadequately treated harvest areas of the past is still a substantial problem as there are an estimated 200,000 acres of this material on National Forest land. Current National Forest timber sales are not a problem as more complete fuel treatment is performed.

Utilization of timber sale residue for energy will provide an economic incentive for fuel treatment on both National Forest and private land. It would reduce the existing discrepancy in treatment standards by land ownership. Benefits would include a reduction in resource losses and fire suppression costs as well as energy yields.

Harvest of biomass from chaparral and other noncommercial sources is another matter. Management regimes have not been established, and harvesting technology has not been evaluated. We believe that the feasibility of energy projects with a short planning horizon should be based on material sources available under present technology and present management strategies.

Long-range energy projections can, however, include assumptions about technological development and management strategies and should include chaparral as a potential energy source.

Insect and Disease Management

Forest sites can support an optimum growth of trees without danger of insect activity. When the volume of biomass on an area exceeds this optimum state, stress in trees will develop. Stressed trees will be removed by insect and disease activity if man does not do it first. Site capability is affected by soil depth, parent soil material, amount of rainfall and other factors. Stands adequately managed through periodic thinnings will optimize growth and be immune to insect activity.

Management of noncommercial stands may result in unexpected problems including insect and disease activity. More information on the management of such stands needs to be generated by research and experience.

The off-site burning of forest residue instead of on-site burning will be more attractive from the standpoint of better air quality and reduced forest fuels. Less injury to remaining trees will also be a benefit.

Stand Improvement

Practical forestry includes the practice of thinning stands periodically to decrease competition and soil nutrient drain, especially from less vigorous trees of the stand, and to optimize growth in dominant or crop trees. Thinning as a normal practice in California stands has been discouraged by the

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[8] Personal communication - unpublished data.

TABLE 2 TEN CATEGORIES OF WOOD RESIDUE IN CALIFORNIA

CATEGORY	ACREAGE*	VOLUME	ROTATION	ANNUAL AVAILABLE DRY TONS IN MILLIONS[9]	
				SHORT TERM 5 yr	LONG TERM 5 yr +
1. Mill Residue	-	SRI 4.6 MM Tons MITRE 8.8 MM Tons F.S. 7.7 MM Tons	-	3.0 (2.72)	1.0 (0.907)
2. Woods Residue	158,630	SRI 5.1 MM Tons MITRE 4.3 MM Tons F.S. 6.5 MM Tons	-	6.5 (5.90)	4.5 (4.08)
3. Conifer Thinnings	158,630	20 Tons/ACRE	60-120 2% Thinning Regime	6.3 (5.71)	6.3 (5.71)
4. Dead & Dying	15.8 MM	1 Billion B.Ft.	-	2.4 (2.18)	1.5 (1.36)
5. Urban Residues	-	500 Tons/Day (Kellbro Corp. Sacramento, Yolo)	- -	4.3 (3.9)	4.3 (3.9)
6. Orchard Prunings	14,000,000 1973 Data (Calif. State Abstracts)	1.5 Tons/Acre	-	2.0 (1.8)	1.0 (0.907)
SUB-TOTAL (MATERIAL AVAILABLE WITH EXISTING TECHNOLOGY)				24.5 (22.22)	18.6 (16.87)
7. Commercial Hardwoods	2,837,000	50-120 Tons/Acre Average 60	90	0	1.9 (1.72)
8. Noncommercial Hardwoods	1.319,000	40-110 Tons/Acre Average 50	40	0	1.6 (1.45)
9. Noncommercial Softwoods	7,532,000	20 Cu.Ft./Acre/Yr. Assume 10 Cu.Ft./Acre/Year	Harvest Annual Growth 140	0	1.0 (0.907)
10. Chaparral	7,554,000	10-46 Tons/Acre Average 20 Tons/Acre	20	0	7.6 (6.89)
SUB-TOTAL (MATERIAL DEPENDENT UPON DEVELOPMENT OF TECHNOLOGY) . .				0	12.1 (10.97)
TOTAL				24.5 (22.22)	30.7 (27.84)

*Acreage figures from U.S. Forest Service forest survey.

9/ Metric tons in parentheses. 1 English ton = 0.907 metric tonnes.
1 metric tonne = 2,204.62 POUNDS.

lack of a market for the products of thinning. Leaving these products on the ground to slowly decay has been prohibitive because of insect and fire threats. The utilization of this material for fuel will have a twofold effect: it will provide fuel from the thinning operations and create faster growth rates in residual stands that will also produce a residue component for fuel purposes. Research studies have indicated a possible doubling of sawlog volume on better sites through planned thinning operations.

A generally more intensive management strategy in commercial timber types will also permit the use of genetically superior stock that will further increase productive capability.

Wildlife Management

The effects of managing for biomass can have profound effects on wildlife, both good and bad. Knowledge of wildlife requirements will permit us to plan judiciously to minimize negative impacts while taking advantage of the positive impacts, as illustrated below:

Commercial forest stands in California still contain many acres of virgin timber that are not prime wildlife habitat. Many chaparral and noncommercial hardwoods stands form impenetrable canopies of low value to wildlife. Management of both these types can increase wildlife populations by:

A. Increasing diversity of habitat and creating greater amounts of edge.
B. Penetration of light in all stands to permit greater production of grasses, forbes, and brush.
C. Creating access in dense chaparral and brush to make new forage, cover and water available.

Precautions need to be taken to provide the following:

A. An adequate number of dead trees to provide for animal dens and cavity-nesting birds. An average of three dead trees per acre in varying degrees of decay will normally support optimum numbers of cavity-nesting birds.
B. Thickets to provide thermal cover in cold weather and fawning grounds in the spring and summer.
C. Adequate downed logs and ground cover for certain species. Two to four logs per acre about 12" in diameter for 40 cubic feet of volume is considered necessary.
D. Minimum road systems to decrease harassment of animals, but also to provide quality hunting experiences.
E. Entry of equipment will need to be restricted during certain times of the year to protect animals during reproductive activities.

Range

The range resource can be significantly increased through management of chaparral and brush systems. Our experience with burned-over chaparral is that about 10 years of good grazing follows the fires. Additional forage can be provided by thinning operations that permit more light to enter stands to produce more grasses and forbs.

Some oak types, such as the Blue and Valley Oaks, will be protected where they form important shade and mast-producing components in oak-grassland ranges.

Range and Wildlife management practices need to be coordinated to provide for both uses.

Esthetics

An additional benefit to forest management will be the improved esthetic qualities of the forest. Dense and chaotic arrangements of slash and brush under commercial stands will be eliminated. A greater diversity of habitat will also increase the non-game species of wildlife that will add to public enjoyment. Young stands will be passable and attractive instead of being impenetrable thickets. Greater control of wildfire and insect epidemics will also add to the esthetic appreciation of the forests.

The use of landscape managment techniques as a tool in the management of the visual resource can do much to make harvest operations blend in with the natural landscape.

ENVIRONMENTAL EFFECTS OF PROPOSED PROJECTS

Harvesting for biomass will have both good and bad effects on the environment.

Man's intrusion into wildland systems usually has a negative effect. We have learned and still are learning to minimize those effects on lands we now consider commercial. Harvesting vegetation as an energy resource will extend our definition of commercial wild land. There are no management prescriptions that can be prescribed carte blanche for all wild lands. Management requirements are site specific and utilization must be tied to the needs of the land.

Some of the obvious effects which need to be planned for and monitored are:

A. Soil compaction will lead to a decrease in infiltration rate of water and a loss of permeability. Compaction will increase runoff, erosion and downstream sedimentation. Compaction decreases survival of germinated vegetative seeds.

Harvesting activities need to be controlled during wet weather to minimize compaction.

Selection of equipment with light load-bearing tracks will help limit compaction to acceptable levels.

B. Reduced vegetative cover will promote both wind and water erosion. Strategic management of cover to provide protection from wind and the effects of running water will be necessary.

Increased siltation from road construction activity is the largest erosion threat. All the experience gained in harvest operations on timber land will have to be applied to protect downstream water values. Downed logs and other vegetation left for wildlife can also serve as physical obstructions to control erosion.

C. Certain micro-ecosystems may be threatened by permitting harvesting areas to become too large. Harvesting prescriptions need to be site specific. Smaller harvest areas will be less economic but will add to vegetative diversity for wildlife and be more attractive.

Certain sites requiring constant vegetative cover will need to be protected from all manipulative activity.

D. Decreased vegetative cover on some sites will result in increased temperatures, drier sites, and reduced vegetative reproduction.

Adequate reproductive knowlege will be necessary to plan for these sites. Nonsprouting species especially will be vulnerable.

E. Nutrient recycling may be a problem on short rotation schedules. On long rotations, adequate mineral and organic nutrients are returned to the soil through leaves, twigs, branches and needles (Zinke 1972). Most of the mineral nutrients found in plants occur in this smaller material. Normal harvest operations also leave this smaller material in the final harvest cut. About three percent of the minerals in the tree are removed in the bole or stem of the tree. This amount is more than adequately replaced from parent soil material. Nitrogen falling with rain and fixed biologically more than adequately replaces the amount removed in long-rotation forestry (Carlish 1976).

Short rotations are, however, another problem and are the reason for the extended rotations suggested for noncommercial categories of biomass. Further research is needed on nutrient recycling problems in short-rotation management regimes.

Whole-tree harvesting likewise poses similar problems of nutrient loss. Thinning operations in long rotation conifer stands do not seem to be a threat but more information is needed on clearcut harvesting of brush and chaparral stands.

F. The regeneration of chaparral stands without fire poses questions that need answering (Philpot 1977):

1. Critical impact on nutrient budgets and productivity.
2. Allelopathic compounds may build up and be maintained leading to lower productivity.

G. Wood has a low sulfur content. Burning it in any of the latest technologically designed furnaces can be done without polluting the surrounding air. Burning it alone or in mixture with coal will reduce the amount of sulfur dioxide, fluorides, and other synergistically formed chemicals that are injurious to man, plants, and animals. Burned alone, it does not require expensive filtration and scrubbing equipment.

Burned in conjuction with coal, it also increases the life of furnace linings and produces a finer, more easily handled ash. (Morford, 1978).

The addition of bark, however, usually results in excessive particulate matter because of included soil particles. Table 3 below illustrates the relative merits of wood to natural gas and oil (Sassenrath 1979).

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TABLE 3 Air Contaminant Emission Rates
(Pounds per million BTU heat input)

Air Contaminants	Wood Fuel [10]	Natural Gas [11]	Fuel Oil 1% Sulfur
Particulate Matter		0.1 [12]	0.01 0.07
Sulfur Oxides	Nil	0.0006	1.05
Carbon Monoxide	0.6	0.017	0.03
Nitrogen Oxides	0.1	0.7	1.0
Hydrocarbons	0.2	0.001	0.007

Burning fuels with dirty bark included necessitates the addition of wet scrubbers, baghouse collectors or electrostatic precipitators, with wet scrubbers being considered the cheapest and most efficient.

Even though new wood-fired boilers posess environmental and financial advantages to fossil fuel boilers, regulatory requirements are not limited to air pollution requirements.

Proponents of wood-fired systems must consider planning regulations, building codes, water quality approval, solid waste disposal requirements, California Environmental Quality Act review and possibly Coastal Commission approval before construction may proceed.

CONCLUSIONS

Harvesting oaks and other natural biomass for energy purposes presents both opportunities and some very real dangers.

The management opportunities are those we have always associated with ideal forest management as seen perhaps in parts of Europe: an esthetically attractive forest, free of fire and insect problems, with optimum growth.

The dangers are those we can envision with a rapidly escalating value for wood fuel that could result in unmanaged and unregulated cutting of natural biomass with consequent soil erosion, loss of wildlife habitat, and other deleterious effects that are unacceptable to the public.

As managers, researchers, teachers, and administrators we all have the obligation to see that we maximize the positive effects of management opportunities while protecting the environment. The vision we should hold before us is of beautiful forests and wild lands, virtually free of fire, contributing in their many ways to a perhaps changed but still good life.

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[10] Values determined by HCAPCD Source Tests.

[11] Values from U.S.-E.P.A. publication AP-42.

[12] Equivalent to 0.04 Grains per cubic oot.

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Quercus
chrysolepis

Economics of Utilizing Oak for Energy[1]

Raymond Stine[2]

Abstract: Utilizing oak as fuel for home heating, as well as commercial energy production, can be shown to be a viable alternative to the use of traditional fuels. An examination of the specific costs involved indicates while the use of oak for commercial energy production is approximately at the break-even point, the production of fuelwood for home consumption is a profitable venture.

INTRODUCTION

Oaks comprise about 80 percent of California's hardwood resource.[3] It can be shown that oak is an economical source of fuel for energy production, not only for individual consumers, but also for commercial energy generation. This paper describes the economics of using oakwood for fuel in two hypothetical situations: 1. currently for individual homeheating and cooking, and 2. potentially for commercial energy generation.

OAK FUELWOOD FOR HOME CONSUMPTION

Today, more and more people are realizing the current benefits of using woodstoves and fireplaces in their homes for direct heating and cooking, thereby offsetting to some degree their rising energy bills. Thus a growing market exists for oak as a fuelwood for home use.

This economic analysis of fuelwood production describes the typical California foothill firewood operation where the operator cuts, splits, loads and hauls his fuelwood product to an urban woodlot for sale. The average selling price is assumed to be $90.00 per cord (Table 1). We will assume that the production per day for a two-man operation is approximately 6 cords, a haul distance of 100 miles round-trip, and a payload of 16 cords per trip. To ease handling and to decrease hauling costs, the cut wood will be air dried prior to transporting.

Table 1--Average cost for producing one cord of oak fuelwood *

Cost Factor	West Sierra & Coast Range		Eastside Sierra
	Tractor	Cable	Tractor
Stumpage	$10.00	$10.00	$10.00
Harvesting Activities			
Fall	1.58	1.58	1.42
Limb	.79	.79	.71
Buck	1.58	1.58	1.42
Lop	.21	.21	.18
Skid	7.69	14.10	6.93
	$11.74	$18.26	$10.66
Processing Activities			
Cut	10.40	10.40	10.40
Split	11.22	11.22	11.22
Load	6.24	6.24	6.24
	$27.86	$27.86	$27.86
Trucking	$18.77	$18.77	$18.77
General Overhead	$ 3.90	$ 3.90	$ 3.53
Total Costs, F.O.B. Woodlot	$72.38	$78.79	$70.02

* See text for cost assumptions.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Wood Energy Forester, California Department of Forestry, 1416 Ninth Street, Sacramento, California 95814.

[3] Bolsinger, Charles L., Oaks in California's Commercial Forests...Volume, Stand Structure, and Defect Characteristics. (Included in this Proceedings.)

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Average selling price Sacramento area (wholesale 1-12-79) = $90.00/cord. Using average selling price, profit equals $11.21/cord for cable and $18.80/cord (average) for tractor sales.

Stumpage Costs

It is assumed that the stumpage price is $20.00 per thousand boardfeet (MBF). It is also assumed that 1 cord equals 500 Bf Scribner Rule. Stumpage will then cost $10.00 per cord.

Harvesting Activities

Costs were adapted from the U.S. Forest Service Timber Appraisal Handbook 1977. These costs include all depreciation on equipment and labor but do not include costs for road construction. To adapt hardwood logging costs from softwood tables, it was decided that the total cost on the average should remain constant although item costs vary. i.e., compared to logging softwoods there is more limbing and lopping during hardwood logging but less bucking prior to skidding. We assumed in this case all additional costs of hardwood logging were cancelled by generally equal cost savings.

Processing Activities

Cutting - For this analysis it was assumed that a person could buck into firewood length 6 cords of wood in an 8-hour day. Using the USFS wage rates of $4.75-$7.30/hr. plus 32.60 percent benefits, the average labor cost equals $7.80/hr.

Splitting - Assuming the average cost of a commercial wood splitter of $2,500 at 10 percent interest plus maintenance costs of 15 percent of the original purchase cost, the splitting costs are:

1. Commercial wood splitter-(5-year life) original cost = $2,500 or $500/year.

   +

   Interest at 10 percent over depreciation period of 5 years = $1,526.28

   +

   Maintenance - (includes maintenance, labor, oil, gasoline, lubrication, and hydraulic fluids) = 15 percent of the original purchase price, price per year = $375/year

   Total cost per year = $1,180.26

Production - For this analysis we can assume 6 cords per day as an average and 240 working days per year

= 6 cords/day x 240 days = 1,440 cords/yea

cost per cord = $\frac{\$1,180.26}{1,440}$ = $.82/cord

2. Labor

   As before, labor at $7.80/hr. x 8 hrs./ day x 240 days/year gives a total yearly costs = $14,976

   and $\frac{\$14,976}{1,440}$ = $10.40 per cord

   Total splitting costs =
   $.82/cord for equipment
   $10.40/cord for labor
   = $11.22/cord

Loading - At loading production of 20 seasoned cords (stacked in semi-trailer) per day (2 persons), costs equal.
$7.80/hr. x 8 hrs./day x 2 persons
= $124.80/day or
$6.24 per cord

The total processing costs for cutting, splitting, and loading = $27.86/cord.

Trucking Costs

Trucking costs for different road conditions are given in Table 2.

Table 2--Trucking costs - Average cost per cord mile [1]

	Total Haul Over Private or USFS Roads		
Cost Haul Class	up to 10 mi.	10 to 30 mi.	30 to 60 mi.
I	.210	.125	.081
II	.262	.167	.108
III	.314	.226	.146
IV	.420	.292	.189
V	.630	.441	.285
VI	.947	---	---

	Partial or Total Haul Over State or County Roads			
Cost Haul Class	up to 10 mi.	10 to 30 mi.	30 to 60 mi.	over 60 mi.
I	.319	.164	.106	.065
II	.346	.208	.134	.077
III	.426	.268	.173	.099
IV	.507	.329	.213	.122
V	.774	.502	.324	.185
VI	1.117	---	---	---

[1] Adapted from U. S. Forest Service Timber Appraisal Handbook (1977) using 1 cord = 500 Bf Scribner.

Cost per cord mile average haul includes compensation insurance, social security, other insurance and taxes and depreciation, but not road construction, road maintenance or reloading.

Cost Haul Class I:

Main highways, two or more lanes wide, cement or bituminous concrete surface, excellent alignment and grades not to exceed six percent. Average truck speed approximately 35 miles per hour. Reduce classification to II for sections of adverse grade over four percent.

Cost Haul Class II:

Secondary highways, 2 lane - combined effect of width surface, alignment and grade not so favorable as in I for high speeds. Average truck speed approximately 30 miles per hour. Reduce classification to III for sections of adverse grade four percent to six percent and to IV for sections over six percent adverse.

Cost Haul Class III:

County roads and Forest Service high-standard utilization *-road - -* well-maintained oiled gravel or earth surface - two lane or wide single lane with intervisible turnouts - good alignment (80 feet radius curves) - grades not exceeding eight percent. Truck speed approximately 20 miles per hour. Reduce classification to IV for sections of adverse grade six percent to eight percent and to V for over eight percent.

Cost Haul Class IV:

Forest Service medium-standard truck trails, single lanes with turnouts not always intervisible - fair gravel or earth surface - broken grades up to 10 percent. Truck speed approximately 15 miles per hour. Reduce classification to V for sections of adverse grade over eight percent.

Cost Haul Class V:

Forest Service low-standard truck trails, single lane with inadequate turnouts, unmaintained earth surface - sharp curvature (40 feet radius) - numerous grades up to 12 percent. Truck speed approximately 10 miles per hour.

Cost Haul Class VI:

Poor, steep, crooked roads nearly impassable for logging trucks, single track roads for one way loaded traffic should be considered as two-lane roads.

For illustrative purposes we shall assume:

1. Haul distance = 100 miles round trip.
2. Payload = 50,000 lbs. or 16 cords.
3. Predominantly haul Class III roads on State and county roads.

Trucking costs using USFS table would equal:

10 mi. @ $.426 x 16 cords = $ 68.16
20 mi. @ $.268 x 16 cords = $ 85.76
30 mi. @ $.173 x 16 cords = $ 83.04
40 mi. @ $.099 x 16 cords = $ 63.36
$ 300.32/trip
or $ 18.77/cord

General Overhead

General overhead figures include scaling but not road construction costs. Adapted from U.S.F.S. Timber Appraisal Handbook (1977).

Total Cost

Total cost figures include equipment depreciation and labor, but do not include costs for road construction and maintenance.

OAK FUELWOOD FOR COMMERCIAL ENERGY PRODUCTION

Anticipating rapidly increasing prices, many sawmills have begun to use more wood chips as boiler fuel to offset higher energy costs and uncertain and interruptable supplies of energy. In fact, currently in California there are 58 lumber mills in 24 counties using wood for on-site production of process steam for operating lumber dry kilns. In addition, the generating capacity of these mills amounts to about 120 megawatts, with an additional 160 megawatts being planned or constructed (See appendix 1). The economic analysis in this example takes the same oak stumpage and working location as in the first example and looks at utilizing it as boiler fuel at an adjacent mill.

For illustrative purposes we let the haul distance be 75 miles round-trip with a 25 ton payload. Interestingly, from actual in-woods chipping performed by the California Department of Forestry, it was determined that possibly the most effective and efficient means

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of reducing the logs to boiler fuel was to transport this material in log form to the mill where it is put through existing hogging equipment. By processing the logs in this way, the large cost and raw size constraints inherent in using an in-woods chipper, are eliminated. This analysis uses green tons or 50 percent moisture content on a wet basis. Seasoning of wood prior to combustion, reducing moisture content and thus increasing boiler efficiency, may be desirable in this case. Finally, as compared to the first example, this case involves more mechanization and incurs greater capital investment.

Table 3--Average costs per ton of producing heat for steam and/or electricity.*

Cost Factor	West Sierra & Coast Range Tractor	West Sierra & Coast Range Cable	Eastside Sierra Tractor
Stumpage	$ 3.80	$ 3.80	$ 3.80
Harvesting Activities			
Fall	.60	.60	.54
Limb	.30	.30	.27
Buck	.60	.60	.54
Lop	.08	.08	.07
Skid	2.92	5.35	2.63
Load	1.03	1.88	.93
	$ 5.53	$ 8.81	$ 4.99
Trucking	$ 6.30	$ 6.30	$ 6.30
Unloading & Handling	$ 1.00	$ 1.00	$ 1.00
Hogging	$ 1.50	$ 1.50	$ 1.50
Conversion to Btu's	$ 1.29	$ 1.29	$ 1.29
General Overhead	$ 1.48	$ 1.48	$ 1.48
Total Costs	$ 20.90	$ 24.18	$ 20.22

Equivalent Heat Value = $21.21/ton.

* See text for cost assumptions.

Using Equivalent Heat Value of $21.21/ton, net economic benefits equal= $2.97/ton for cable and $.35/ton (average) for tractor sales.

Stumpage

Again it is assumed that the stumpage price is $20.00 per thousand board feet (MBF).

It is also assumed that there are approximately 5.26 green tons per thousand board feet resulting in a stumpage cost of $3.80/green ton.

Harvesting Activities

Costs were adapted from the U. S. Forest Service Timber Appraisal Handbook (1977) usin cord weight of 5,270 pounds (green wt.) and 1 cord equaling 500 board feet Scribner Scale All costs are included except road construction.

Trucking Costs

Trucking costs, adapted from the U. S. Forest Service Timber Appraisal Handbook (1977), are given in Table 4.

Table 4--Trucking cost per ton mile.[1]

Total Haul Over Private or USFS Roads

Cost Haul Class	up to 10 mi.	10 to 30 mi.	30 to 60 mi.
I	.08	.05	.03
II	.10	.06	.04
III	.12	.08	.06
IV	.16	.11	.07
V	.24	.17	.11
VI	.36	--	--

Partial or Total Haul Over State or County Roads

Cost Haul Class	up to 10 mi.	10 to 30 mi.	30 to 60 mi.	over 60 mi.
I	.12	.06	.04	.02
II	.13	.08	.05	.03
III	.16	.10	.07	.04
IV	.19	.12	.08	.05
V	.29	.19	.12	.07
VI	.42	--	--	--

[1] Adapted from U. S. Forest Service Timber Appraisal Handbook (1977).

Cost per ton mile average haul, includes compensation insurance, social security, othe insurance and taxes and depreciation, but do not include road construction, road maintenance or reloading.

For illustrative purposes we assumed:

1. 75 mile haul distance - round trip.
2. 25 ton payload
3. Haul class III on State and county roads.

In this **case** - trucking costs would equal:

10 mi. x 25 tons x \$.16/tm = \$40.00
20 mi. x 25 tons x \$.10/tm = \$50.00
30 mi. x 25 tons x \$.07/tm = \$52.50
15 mi. x 25 tons x \$.04/tm = \$15.00
Total \$157.50

$$\frac{\$157.50}{25 \text{ tons}} = \$6.30/\text{ton}$$

Unloading and Handling Costs

Actual cost of unloading logging trucks and transporting material to hogging equipment at Michigan-California Lumber Company, Camino, California.

Hogging of Boiler Fuel

Actual cost of hogging woody material at Michigan-California Lumber Company, Camino, California. Includes costs of hogging and transportation of hog fuel to boiler.

Conversion Costs

Conversion to Btu's - using actual cost of conversion of \$0.217/million Btu @ 50 percent moisture content (Michigan-California Lumber Co., Camino, California) - and assuming 4,250 Btu/lb. @ 50 percent moisture content and boiler efficiency of 70 percent. Net useful energy = 4.250 Btu/lb. x .70 = 2,975 Btu/lb. or 5.95 mm Btu/ton. Cost per ton = 5.95 mm Btu/ton x \$0.217/mm Btu = \$1.29/ton at 50 percent moisture content.

Overhead Costs

General overhead figures include scaling but not road construction costs. Adapted from U.S.F.S. Timber Appraisal Handbook (1977).

Total Cost

Total cost figures include equipment depreciation and labor but do not include costs for road construction and maintenance. Adapted from U.S.F.S. Timber Appraisal Handbook (1977).

Equivalent Heat Value

The equivalent Heat Value was calculated from the USDA Forest Service Fuel Value Calculator using actual September 1978 #6 Fuel Oil Value of \$20.01 and assuming a six percent increase to April, 1979 equaling \$21.21.

CONCLUSION

The economic analysis of utilizing California oak for private consumption as well as commercial energy production indicates that in each case the value of each product produced either meets or exceeds its production cost.

LITERATURE CITED

U.S.D.A. Forest Service, Timber Sale Preparation and Appraisal Handbook - FSH2 - 2425 - R5, (1977).

U.S.D.A. Forest Service, Fuel Value Calculator, Developed by A.B. Curtis, Jr. Revised February, 1978.

APPENDIX

Present Wood Derived Power Capacity

A significant amount of energy is already being generated from industrial wood waste. Fifty-eight mills in 24 counties are using wood for power generation in one form or another. Most of the 2,606,700 tons of wood waste being used each year is used for generating steam, either to operate lumber dry kilns or for other process steam uses.

Electricity generation capacity amounts to 123.5 megawatts, with an additional 160 megawatts being constructed or planned. An additional 3 million tons of wood waste is presently being disposed of by incineration or by burial in landfills. Much of this additional residue volume had previously been directed into the pulp market. That market is presently oversupplied and depressed.

A detailed tabulation of wood industries creating and/or using wood waste for power has been compiled by the Solid Waste Management Board, California Department of Forestry, and the California Energy Commission. It is reprinted here.
It is reprinted here as Appendix 1.

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WOOD FUELED BOILER LOCATIONS
COMPILED BY STATE SOLID WASTE MANAGEMENT BOARD

County	Company Name & Plant Type	Location	Lum. Prod. (10^6/YR 1976)	WW Fuel (W)ood (B)ark	Ind. Boiler Capacities (10^6 Btu/HR)	Total Steam Prod. Cap. (10^3 T/YR)	Total WW Used (10^3 T/YR)	Max. Fuel Boiler Inpt. (T/HR)	Elec. Gen. (MW) (P)roposed (E)xisting
AMADOR	Am. Forest Prod.	Martell		WB	17,68	85	57.4	10.7	5 (P)
	SAW		66.7 bf						
	PAR		85^{e} ft^2						
	SPL		68.3^{a}ft^2						
	BAR		-						
	P & M Lumber	Pioneer							
	SAW		50 bf						
	BAR		-						
BUTTE	Cal Oak Lumber (SAW)	Oroville	5.5 bf						
	Diamond Int'l (SAW)	Oroville	29 bf						
	Louisiana-Pac	Oroville		W	120	120	26.9	5.6	30-40 (P)
	SAW		200 bf						
	HAR		140^{b} ft^2						
	Wickes Forest Ind. (BAR)	Oroville	-						
	Diamond Int'l (RMN)	Chico	-	W	(11)	(11)	9.6	1.1	
CALAVERAS	Snider Lumber (SAW)	Wallace	22 bf						
	Brunswick Timber (SAW)	San Andreas	1.9 bf						
CONTRA COSTA	Fibreboard	Antioch	pulp						
DEL NORTE	Simonson Lumber (SAW)	Smith River	53.5 bf	WB	17	17	9.0	1.0	8 (P)
	McNamara & Peepe Lum.(SAW)	Crescent City	28.8 bf						
	Miller Redwood	Crescent City							
	SAW		42.3 bf						
	SVM		3.7^{b}ft^2						
	Northcrest (SAW)	Crescent City	16 bf						
	Simpson Timber	Klamath	20.5 bf						
	Hambro Forest Prod. (PAR)	Crescent City	24.9^{e}ft^2	W	33	33.	2.5	1.8	
	Westbrook (PLY)	Crescent City							
EL DORADO	Golden State Bldg. Prod.	Shingle Springs							
	SAW		36.6 bf						
	SVM		15 bf						
	Placerville Lumber	Placerville			(15)	(15)	19.4	(2.9)	
	SAW		17 bf						
	BAR		-						
	Mich-Cal Lumber	Camino		WB	72,72,144	288	101.4	18	
	SAW		53.4 bf						
	BAR		-						
FRESNO	Wickes Forest Ind. (SAW)	Auberry	48.9 bf						
	Am. Forest Prod. (SAW)	Dinkey Creek	28 bf						
	Wickes Forest Ind. (SAW)	Fresno	15 bf						
GLENN	Louisiana-Pac (SAW)	Elk Creek	50 bf	WB	13	13	8.7	(2.2)	
HUMBOLDT	Arcata Redwood (SAW)	Orick	61.2 bf						
	Cal-Pacific (SAW)	Orick	31 bf						
	Cal-Pacific (SAW)	Hoopa	27 bf						
	Masonite	Hoopa							
	SAW		32.6 bf						
	SVM		75^{b} ft^2						
	Cal-Pacific	Blue Lake	-						
	McIntosh Lumber (SAW)	Blue Lake	20.9 bf						
	Simpson Timber (SAW)	Korbel	98 bf	W	24	24	8.6	1.3	20 (P)
	McNamara & Peepe Lum. (SAW)	Arcata	41.8 bf	WB	15	15	1.8	0.9	
	Sierra-Pac	Arcata							
	SAW		41.8 bf						
	SPL								
	Simpson Timber (PLY)	Arcata	120^{a} ft^2	WB	91,102	193	37.1	10.8	
	Trend Lumber (SAW)	Arcata	69.3 bf						
	Louisiana-Pac	Samoa		WB	55,340,235,320	950	171.5	50.2	42 (E)
	SAW		88 bf						
	SPL		125^{a} ft^2						
	Schmidbauer Lumber (SAW)	Eureka	(37) bf			80^{c}			
	Crown-Simpson	Fairhaven	pulp	WB	450	450	149.1	18.9	19 (E) 20-40 (P)
	Humboldt County	Eureka	-						
	Eel River Sawmills (SAW)	Fortuna	75 bf						
	Pacific Lumber (SAW)	Fortuna	30 bf						
	Halvorsen Lumber (RMN)	Alton	-						
	Carlotta Lumber (SAW)	Carlotta	27.6 bf						
	Louisiana-Pac (SAW)	Carlotta	54 bf						
	Louisiana-Pac (SAW)	Dinsmore	30 bf						
	Pacific Lumber	Scotia		WB	150,250,120, 120,120	760	143.0	42.2	22.5 (E)
	SAW		104 bf						
	SPL		-						
	Eel River Sawmills (SAW)	Redcrest	20.9 bf						
	Georgia-Pac (SAW)	Myers Flat	29 bf						

County	Company Name & Plant Type	Location	Lum. Prod. (10^6/YR 1976)	WW Fuel (W)ood (B)ark	Ind. Boiler Capacities (10^6 Btu/HR)	Total Steam Prod. Cap. (10^3 T/YR)	Total WW Used (10^3 T/YR)	Max. Fuel Boiler Inpt. (T/HR)	Elec. Gen. (P)roposed (E)xisting
	Louisiana-Pac (SAW)	Alderpoint	35 bf						
	Blue Ox Lumber (SAW)	Eureka	0.8 bf						
	Louisiana-Pac (SAW)	Big Lagoon	33 bf						
	Simpson Timber (SPL)	Fairhaven		WB	62,62	124	34.2	6.8	
	Louisiana-Pac (PAR)	Arcata	184^e ft^2	WB	(17)	17	13.9	1.7	
	Twin Harbor (HAR)	Dinsmore	25 ft^2						
	Twin Parks (SAW)	Arcata	7.8 bf						
	Dimmick Forest (BAR)	Garberville	-						
KERN									
	Louisiana-Pac (SAW)	Inyokern	50 bf	WB	22	22	5.2	1.7	
LASSEN									
	Main Ind. (SAW)	Beiber	21 bf						9 (P)
	Trin-CO Forest (SAW)	Little Valley	6 bf						
	Coin Lumber	Susanville		WB	40	40	10.2	(1.8)	3 (P)
	SAW		39.6 bf						
	BAR		-						
	Sierra-Pac	Susanville		WB	26,26,26, 26,60	164	136.8	(8.0)	4-10 (E)
	SAW		96 bf						
	BAR								(?)
LOS ANGELES									
	Birchwood of LA (HPL)	Los Angeles	4^f ft^2						
	Sunset Plywood (HPL)	Los Angeles							
	Plywood Prod. (HPL)	Santa Fe Springs							
	General Veneer Mfg.	South Gate							
	SPL								
	HVM								
	Plywood Mfg. of Calif.	Torrance							
	SPL		500^a ft^2						
	HPL		6.5 ft^2						
MADERA									
	AM. Forest Prod. (SAW)	Oakhurst	30 bf						
	Yancey Lumber (SAW)	Madera	22 bf						
	Am. Forest Prod. (SAW)	North Fork	36.5 bf	WB	20	20	10.1	1.5	
	Norby Lumber (SAW)	North Fork	9.4 bf						
	Carney & Co. (BAR)	Madera	-						
MARIPOSA									
	Carter's Sawmill (SAW)	Mariposa	.004 bf						
MENDOCINO									
	Louisiana-Pac (SAW)	Covelo	35 bf	WB	19,19,19	57	22.7	3.2	
	Philo Lumber (SAW)	Laytonville	26 bf						
	Hardwood Products (SAW)	Branscomb	48 bf						
	Hardwood Products (SAW)	Willits	29.4 bf						
	Louisiana-PAC (SAW)	Willits	40 bf						
	Little Lake Ind. (RMN)	Willits	-	W	23	23	(21.4)	1.2	
	Georgia-Pac (SAW)	Ft. Bragg	116 bf	WB	210,210,43, 43	506	165.0	29.6	15 (E)
	Louisiana-Pac (SAW)	Ft. Bragg	40 bf						
	Louisiana-Pac (SAW)	Potter Valley	35 bf	WB	66	66	8.4	0.9	
	Hamson Lumber (SAW)	Redwood Valley	(9.3) bf						
	Louisiana-Pac (SAW)	Capella	13.2 bf^c						
	Masonite (SAW)	Capella	71 bf						
	Louisiana-Pac	Ukiah		W	68	68	21.6	2.7	
	SAW		50 bf						
	PAR								
	Philo Lumber (SAW)	Philo	23 bf						
	Masonite	Ukiah		WB	115,115,235	465	21.4	3.2	
MODOC									
	Suprise Valley Lumber(SAW)	Cedarville	6 bf						
	Calandor Pine (SAW)	Alturas	22 bf	WB	26,5,5	36	25.0	3.5	
	Edgerton Lumber (SAW)	Adin	8 bf						
NEVADA									
	Sierra Mr. Mills (SAW)	N. San Juan	34 bf	W	25,25	50^d	7.0	3.5	
	Erickson Lumber (SAW)	N. San Juan	5.3 bf						
	Bear River Lumber	Grass Valley							
	SAW		32.7 bf						
	BAR		-						
	Yuba River Lumber (SAW)	Grass Valley	(28) bf						
	Douglas Lumber (SAW) (Fibreboard)	Truckee	44.2 bf	WB	55,93	148	67.2	10	
ORANGE									
	Shelburne Ind. (HPL)	Santa Ana	0.2^a ft^2						
PLACER									
	Am. Forest Prod. (SAW)	Foresthill	38 bf	WB	40,23	63	23.7	3.9	
	Am. Forest Prod. (SAW)	Foresthill	32 bf						
	Fibreboard (PAR)	Rocklin	60^e ft^2		65	65	30.0	2.5	5 (P)
	Mountain Milling (SAW)	Rocklin	(62) bf						
	Lausmann Lum. & Mold (SAW)	Loomis	28 bf						
	Brunswick Timber (RMN)	Auburn	-	W	38	38	17.2	2.4	

County	Company Name & Plant Type	Location	Lum. Prod. (10^6/YR 1976)	WW Fuel (W)ood (B)ark	Ind. Boiler Capacities (10^6 Btu/HR)	Total Steam Prod. Cap. (10^3 T/YR)	Total WW Used (10^3 T/YR)	Max. Fuel Boiler Inpt. (T/HR)	Elec. Gen. (P)roposed (E)xisting
PLUMAS									
	Collins Pine	Chester		WB	54,54,96	204	81.2	11.5	3 (E)
	SAW		75.6 bf						
	PAR		25^{e} ft^{2}						
	Louisiana-Pac (SAW)	Greenville	25 bf						
	Louisiana-Pac (SAW)	Crescent Mills	60 bf	WB	28	28	13.9	1.8	
	Sierra-Pac (SAW)	Quincy	36.9 bf		60	60	53.0	8.1	10 (P)
	Essex Lumber (SAW)	Quincy	(25) bf						
	Sierra-Pac (SAW)	Sloat	34.4 bf						
SACRAMENTO									
	Black Diamond (SAW)	Sacramento	47.2 bf						
SAN BERNARDINO									
	Golden Bear Forest Prod.	Redlands							
	SAW		18 bf						
	BAR		-						
	Twin Peaks Timber Prod. (SAW)	Twin Peaks	20 bf						
SAN DIEGO									
	Solana Lumber (SAW)	Solana Beach	(6.2) bf						
SAN JOAQUIN									
	Cal Cedar Prod. (RMN)	Stockton	-		41	41	7.4	1.3	
	Pacific Paperboard	Stockton		paper					
SANTA CRUZ									
	Big Creek Lumber	Davenport							
	SAW		16 bf						
	BAR		-						
	Holmes Lumber (SAW)	Scotts Valley	8 bf						
SHASTA									
	Fibreboard	Burney		WB	39,39	78	44	5.0	
	SAW		40 bf						
	HPL		72^{f} ft^{2}						
	Publisher's Forest (SAW)	Burney	98.5 bf	WB	8,8,8,133	157	111	13.3	
	Calavaras Cement (CEM)	Project City	-				25		
	Champion Int'l	Anderson		WB	122,76,82	280	163.0	16.2	
	SVM		120^{a} ft^{2}						
	SAW		69 bf						
	Sierra-Pac (SAW)	Central Valley	30 bf	WB	38	38	39.4	6.0	
	Collier Lumber (SAW)	Redding	12 bf						
	Hudson Lumber (SAW)	Anderson	30 bf						
	Kimberly-Clark	Anderson		WB	16,16,16, 16,16	80	120.8	11.5	2-4 (E)
	SAW		65 bf						
	BAR		-						
	Paul Bunyan Lumber	Anderson		WB	13	13	27.0	17.4	
	SAW		40.4 bf.						
	BAR		-						
SIERRA									
	Holstrom Lumber (SAW)	Sattley	8.2 bf						
	Sierra-Pac (SAW) ?	Loyalton	50 bf^{c}		39	39	26	4.2	
SISKIYOU									
	SWF Plywood	Happy Camp			40	40	36	(5.5)	
	SVM		1.0^{a}ft^{2}						
	SAW		60.7 bf						
	Hi-Ridge Lumber (SAW)	Yreka	30.5 bf						
	Pine Mountain (SAW)	Yreka	28 bf						
	Int'l Paper	Weed			300	28.2	2.7		4.5 (E)
	SAW		79 bf						
	SVM		46^{b} ft^{2}						
	Cooper's Mill	Mt. Shasta							
	SAW		27 bf						
	BAR		-						
	Kimberly-Clark (SAW)	Mt. Shasta	61.6 bf						
	U.S. Plywood (Champion)SAW	McCloud	120 bf	WB	25,25,38,38	126	112	13	3.5 (E)
SONOMA									
	Preston Lumber (SAW)	Cloverdale							
	G & R Lumber (SAW)	Cloverdale							
	Masonite (SAW)	Cloverdale	104.5 bf						
	Berry's Sawmill	Cazadero							
	SAW		6.8 bf						
	BAR		-						
	Calico Hardwoods (SAW)	Windsor	0.1 bf						
	Chenoweth Lumber (SAW)	Bodega	10 bf^{c}						
	Sonoma Pacific (SAW)	Schellville	10 bf						
	Louisiana-Pac (RMN)	Cloverdale	-	W	9.3	(9.3)	6.1	(0.9)	
	Cloverdale Prod.	Cloverdale							
	SVM		0.6^{b}ft^{2}						
	SPL		30^{a} ft^{2}						

County	Company Name & Plant Type	Location	Lum. Prod. (10^6/YR 1976)	WW Fuel (W)ood (B)ark	Ind. Boiler Capacities (10^6 Btu/HR)	Total Steam Prod. Cap. (10^3 T/YR)	Total WW Used (10^3 T/YR)	Max. Fuel Boiler Inpt. (T/HR)	Elec. Gen. (MW) (P)roposed (E)xisting
TEHAMA									
	Diamond Int'l	Red Bluff		WB	78,78,78,78	312	170.0	22.3	
	SAW		111 bf						
	SPL		70^{a} ft^2						
	Louisiana-Pac (SAW)	Red Bluff	88 bf	W	37	37	7.5	2.3	
	Crane Mills	Paskenta		W	18	18	8.8	1.0	
	SAW		25 bf						
	BAR		-						
	Harris-Crestline (SAW)	Corning	13 bf						
TRINITY									
	SWF Plywood (SAW)	Burnt Ranch	32.7 bf	WB	8,16	24	6.3	1.2	
	SWF Plywood	Salver							
	SAW		4.4 bf^{c}						
	SVM		117^{b} ft						
	Cal-Pacific (SAW)	Weaverville	20 bf						
	Hyampom Lumber (SAW)	Hyampom	25 bf						
	Sierra-Pacific (SAW)	Hayfork	69.4 bf	W	12,13	25	6.9	1.6	
	Kimberly Clark (SAW)	Wildwood	29 bf^{c}						
	Brooking's Plywood (PLY)	Salyer			6,8,8	22	2.1	0.5	
TULARE									
	Wickes Forest Prod.	Dinuba							
	SAW		47 bf						
	BAR		-						
	Am. Forest Prod. (SAW)	Johnsondale	21 bf						
	Sierra Pacific	Terra Bella							
	SAW		61.6 bf						
	BAR		-						
TUOLOMNE									
	Halter & Co. (SAW)	Sonora	(15.5) bf						
	Snider Lumber Prod.	Chinese Camp							
	SAW		16.5 bf						
	BAR		-						
	Fibreboard	Keystone	37 bf						
	Fibreboard	Standard		W	130,86	216	104.8	15.7	6-20 (P)
	SAW		78 bf						
	SPL		65.6^{a}ft^2						
	SVM								
	BAR								
	Whitt Mfg.	Sonora	(7.8)bf						
YUBA									
	Diamond Int'l (SAW)	Marysville	40 bf	W	60	60	20.8	(4.1)	
	Erickson Lumber (SAW)	Marysville	39 bf	W	(23)	(23)	24.0	(1.8)	
	Sierra Mt. Mills (SAW)	Comptonville	15 bf						
TOTAL							2,606.7		

Assumptions:
a 3/8" basis
b 1/8" basis
c 1975
d Jeffrey's data
e 3/4" basis
f 1/4" basis

( ) Calculated value based upon:
1. 1 LB wood produces 5 LB steam
2. Boiler operation of 365 days/year 24 hours/day
3. Actual steam production is approx. 75% of capacity
4. Plant production for 310 days/year

Plant Types:
SAW sawmill
PAR particleboard plant
SPL softwood plywood plant
HAR hardwood plant
SVM softwood veneer mill
BAR bark plant
PLY plywood plant
RMN remanufacturing
CEM cement plant
HPL hardwood plywood plant

Quercus kelloggii

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Observations on Wildlife Abundance in Several California Black Oak Habitats in Northern California[1]

Steven J. Kerns[2]

Abstract: To determine the value of oaks to wildlife, five California black oak habitats and two "edge" areas were evaluated from April to June 1977 on the Shasta-Trinity National Forest. In each, sampling techniques included: a 3-acre bird transect, a 16-acre small mammal trapping area utilizing 9 Havahart traps, a small-rodent trapline with 20 Havahart traps, one 660 foot-long deer-elk transect, and one bait station designed to obtain fur samples. Mature oaks with scattered conifers and a moderately heavy understory of shrubs and grasses ranked highest for number of species and abundance of birds, rodents, deer, and elk. Next in importance was the edge between the above type and young oak stands, followed by the edge between mature oaks and conifers.

My first involvement with oaks came in 1977 when a forester asked, "How valuable are California black oaks to wildlife?" A moment later he stated, "sixty thousand acres of black oak on the Shasta-Trinity National Forest are currently categorized as understocked backlog, and thus are subject to conversion to conifers." Because much of this land was suspected of being prime wildlife area, he got my immediate attention.

Soon after his pronouncement, this forester requested input from wildlife biologists to the potential conversion program. The biologists' response was to evaluate which California black oak habitats were most beneficial to a wide range of wildlife species. Between April and June 1977 a 267-acre site representing a typical conversion area became a wildlife observation area. Within it, National Forest and California Department of Fish and Game Wildlife Biologists identified five oak habitats and two transition or "edge" areas utilized by wildlife.[3]

THE STUDY

This area is located on the east fork of Squaw Creek, which is a major tributary of the Sacramento River. Elevations range from 2,000 to 2,700 feet. Aspect is basically southwest with an average slope of 25 percent. One main draw and several smaller draws make up the drainage. Three permanent water seeps are located within one draw,with the others having only intermittent flows. Although not quantified, some acorns were produced by California black oak in the fall of 1976. At the time of sampling in the study area, all but inviable acorns had disappeared. Newly dug holes and recently broken acorn shells on the ground indicated, however, that viable acorns remained, either buried or hidden under leaves.

Temperatures in the area range from 105 degrees F. in the summers to 15 degrees F. in the winters. Precipitation ranges between 35 and 60 inches each year.

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[1] Presented at the Symposium on Ecology, Management and Utilization of California Oaks, June 26-28, 1979, Claremont, California.

[2] Wildlife Biologist, Shasta-Trinity National Forest, Forest Service, U.S. Department of Agriculture, Redding, California.

[3] James Gordon, USFS, Modoc National Forest, Alturas, California,and Charles Graves, California Department of Fish and Game, Chico, California, aided in this portion of the study.

Vegetation is highly variable in the area. Large pure stands of any single species are rare. Most of the area is composed of small stands or groups of conifers and oaks. Within each black oak group, age generally is constant. This is because nearly all stands are of sprout origin (McDonald 1969). A major disturbance in the past killed the trees to groundline from where they sprouted to form the trees of today. As disturbance tends to be frequent in this elevation zone, the vegetation is made up of a mosaic of species and age classes.[4/] Often this pattern is indicative of differences in soils, old fire patterns, or local snow storms which cause severe breakage.

An inventory of the observation (study) area was:

Category	Acres	Percent
Unproductive forest land	69	26
Stocked commercial forest land	62	23
Land with commercial size black oak	44	17
Non-stocked commercial forest land	92	34
	267	100

Overall, California black oak comprises about 48 percent of the overstory canopy, with the remainder occupied by conifers, other hardwoods, woody shrubs, and rock outcrops. In addition to the even-aged trees, California black oak stands often contain seedlings and seedling-sprouts and occasionally an old monarch 250 to 350 years old.

Defining and recognizing groups of vegetation proved to be difficult, but eventually vegetational groups of specific stand structure and species composition were identified. These were characterized further by understory plant species. Further refinement of the groupings led to five broad but recognizably different habitats and two major transition or "edge" areas. These were then keyed to specific locations on the ground and described as mature oak, mature conifer-decandent oak, mixed oak-conifer, young oak, mature oak-conifer, mature oak-conifer edge, and mature oak-young oak edge.

Mature Oak

This area was located on a south aspect with slopes of 10 to 90 percent. The overstory was mature California black oak (80- to 200-years old) which comprised 90 percent of the crown canopy. A few scattered Douglas-firs and ponderosa pines and several snags added variability to the overstory. Understory vegetation consisted of deerbrush, perennial grasses, and a few herbaceous species (fig. 1).

Figure 1--Heavy understory vegetation, well developed crowns and good mast production typify a mature oak stand.

Mature Conifer-Decandent Oak

In this habitat, the overstory was 80 percent with a few remnant overmature oaks (fig. 2). The understory consisted of 80 percent duff and litter, and 20 percent shade-tolerant shrubs such as poison oak, California hazelnut, and California storax.

[4/] McDonald, Philip M. California black oak. In Forest Cover Types of North America. Society of American Foresters. Revised description 1979.

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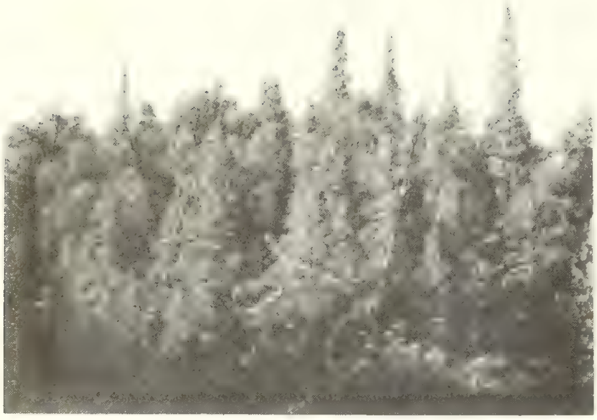

Figure 2--Only a few decadent oaks remain in the mature conifer stand.

Mixed Oak-Conifer

Twenty percent of this area was rock outcrops and scattered patches of brush and grass. Cover on the remaining 80 percent consisted of small stands of canyon like oak, California black oak, ponderosa pine, and shrub Oregon white oak. In places the understory was extremely heavy with several grasses, deerbrush, shrub Oregon white oak, bigleaf maple, poison oak, and other shrubs being present (fig. 3).

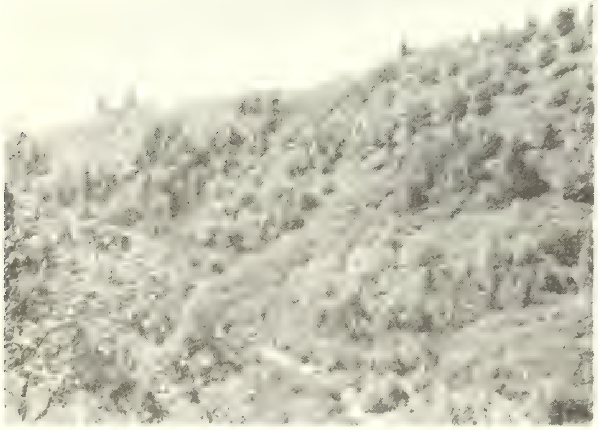

Figure 3--A variable blend of tree and shrub hardwoods, other woody shrubs, and conifers make up the mixed oak-conifer habitat.

Young Oak

Here California black oak, 80- to 100-years old, comprised 90 percent of the overstory. A few small poison oaks and other lesser vegetation were scattered in the understory (fig. 4). The study area consisted of a 16-acre block located on a north-south bearing.

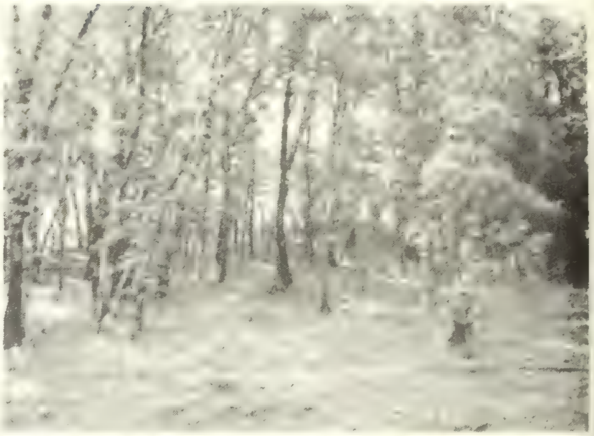

Figure 4--Young oak stands are characterized by a relatively closed canopy with little understory vegetation.

Mature Oak-Conifer

This area was located on a north-south ridge with a south aspect. It consisted of about 25 acres of ponderosa pine and California black oak. Each of these species contributed about equally to canopy cover (fig. 5). The sparse understory of shrubs and grasses, however, was more typical of that found under pines.

Mature Oak-Conifer Edge

California black oak and conifers sometimes occupy different but predictable portions of the landscape. The oak is found on hotter west and south aspects and where the site is of lower quality. Consequently, California black oak will occupy upper slopes and ridgetops with conifers below. Where the mature oaks and conifers meet, a narrow edge habitat is created which often is only 50- to 100-feet wide. Less common, but wider edge occurs when groups of conifers and oaks intermingle, or when they gradually blend together. In this habitat, grasses, California hazelnut, bigleaf maple, and various other shrubs and herbaceous plants grow under an overstory of mature oaks and conifers.

Figure 5--A 50-50 blend of mature California black oaks and conifers is common along the Sacramento River north of Lake Shasta.

Mature Oak-Young Oak Edge

This edge, although narrow, also creates a specific habitat for wildlife. Under the more open stand of mature oaks, the understory is well developed; under the dense young stand, it becomes sparse. Many species of plants are found in this habitat, including a few unique to it.

Within each habitat type, wildlife biologists employed five sampling techniques:

Bird Transects - Each consisted of three acres and 21 monitoring stations. The transect was "read" by spending three minutes at each station and noting the species and location of all birds seen or heard. Transects were visited several times each week from April through June. Birds seen were tallied and plotted on a scaled diagram of the transect. If a bird was consistently observed in a given area, that area was considered as a breeding territory. Next, locations also were noted if they were within the transect boundaries.

Squirrel Traps - Each trapping site consisted of a 16-acre area. This size was recommended by a California Department of Fish and Game biologist as being sufficient to obtain needed information. Nine wire-mesh Havahart traps were systematically located in each. They were baited with walnuts for two weeks before actual trapping to give the squirrels sufficient time to become accustomed to the traps and attracted to the bait. Sampling was done 4 days per week during the study.

Rodent Trap Lines - Each of these lines consisted of 20 Sherman live traps placed at 40-foot intervals. Each line was located in the middle of each bird transect. Peanut butter and oatmeal was the bait. Animals caught, including deer mice, California meadow mice, wood rats, and voles, were recorded, toe clipped, and released.

Deer-Elk Transects - These transects followed that recommended in the U.S. Forest Service Range Analysis Handbook. Ten sampling points were installed along transects at 66-foot intervals and monitored weekly. At each, all elk and deer pellet groups were counted, and all vegetation according to condition, trend, and composition was noted within a 70.5 inch radius. This radius equals 1/400 acre, and with ten plots amounts to 1/40 acre sampled. Collected data gave number of plants and animal-days of use in each acre of sampled habitat.

Fur (Bait) Stations - Six bait stations were hung from tree branches randomly located in different cover types. Each station consisted of salmon wrapped in a burlap sack suspended from a tree limb by wire. Barbed wire was wrapped around the branch on which the bait was hung. Thus fur-bearing "raiders" had to go across the barbed wire to reach the bait.

Because of the preliminary nature of the study and because of budgetary limitations, replications of study areas were not possible. The findings that follow are based on a combination of data from the sampling techniques as well as visual observations.

RESULTS

In this study mature California black oak stands proved to be the most valuable habitat for wildlife. The large, tall trees with well-developed crowns frequently yield large numbers of acorns which are a prime food source for many species of wildlife. The associated understory vegetation also seems to be an important element contributing to the value of the habitat. Where the understory is abundant, there is a large number of wildlife species. Another reason is vertical edge (that created by the stratification of vegetation between the forest floor and the forest canopy). Such edge creates additional niches especially for birds and squirrels (Leopold 1933). This, coupled with a variety of understory plant species and their different berries, seeds, stems, and leaves, combined to create desirable wildlife habitat. Shelter from predators and storms, and suitable microhabitat for resting and breeding are additional reasons. The mature California black oak habitat had the highest use by deer, elk, birds, and small mammals.

The second most important oak habitat for wildlife is the edge between mature oak stands and young oak stands. Here it is the variety in environment and foodstuffs that is important. Mature oaks give openness and hence warmer temperatures, longer visual distances, more plentiful acorns, and a large variety of fruits and greenery from the abundant understory vegetation. Younger oaks tend to form more dense stands and have tight narrow crowns with little space between them. Only a small amount of sunlight is able to penetrate into these dense stands and the environment so formed is cooler and darker than that of the mature oaks. The lower vegetation on the forest floor tends to be sparse and poorly developed. Few acorns or fruits are formed in this environment. In intermediate environments, foodstuffs from the more open and more closed environments are available, although to a lesser degree, as well as foodstuffs from different numbers and perhaps different species unique to the intermediate environment. Bird utilization within the mature oak-young oak edge was nearly the same as in mature stands, but rodent, squirrel, deer, and elk abundance declined.

The third most important habitat is the edge between mature oaks and conifers. This edge can be very sharp with a stand of oaks abruptly ending and a stand of conifers beginning. Often it can be an intermingling of groups, and sometimes even a gentle blending of conifers and hardwoods.

Where the transition is abrupt, the edge effect is found within a very narrow zone but it receives heavy usage as animals move between conifers and oaks. The intermingling of groups, or mosaic edge, is much wider, and within it the highest squirrel populations were observed. The reason seems to be that the combination of oaks and conifers provide excellent aerial pathways, as well as good opportunities for denning, feeding, and loafing High use also was observed by avian species as well.

The fourth most important habitat is found where young oaks are the dominant cover. Here, the entire stand typically is quite dense, often with a closed canopy. Little sunlight reaches the forest floor, and understory vegetation is limited to scattered plants. This habitat is utilized heavily by birds but very little by small rodents, squirrels, deer, or elk.

The mature oak-mature conifer habitat in which the oak grows as single trees, clumps, or or groves generally is quite dense. Seed production from both conifers and oaks is high and tree seed, rather than seed from understory species, influences the kind and amount of wildlife. Bird and gray squirrel utilizatio is good within this area. In locales where sunlight penetrates to the forest floor, a few brush and grass species become established and are utilized by deer and small rodents.

The remainder of the habitats studied are used marginally by wildlife as a whole. The mixed oak-conifer assemblage is extremely variable. Large variation in site quality due to strong dissection of the land and a wide variety of slopes and aspects influence the amount and patterning of the vegetation. Shrub Oregon white oak provides a unique cover as it forms an almost impenetrable "jungle" to man or large animals. Acorn production of this shrub in the study area is unknown, but thought to be poor and infrequent. Most, but not all, of the oak trees are young in this area, and thus acorn production overall is low. Species of nearly all the wildlife evaluated in this study utilized this area to some degree. None, however, found it to be preferred habitat. In spite of the large diversity of environments, lack of overstory and understory foodstuffs could have been limiting.

As conifers mature and increasingly occupy the site, the oaks begin to fade from the landscape. In the mature conifer-decadent oak habitat, an abundance of dead wood is found along with a high amount of woodpecker activity. Because the understory tends to be sparse with little food available for wildlife, ground-dwelling creatures are infrequently observed.

Diversity in environment within a given habitat seems to increase use by wildlife. Thus overstory-understory combinations appear beneficial. A much more important factor, however, appears to govern wildlife abundance and use. And that is acorns. Large California black oaks with well developed crowns are consistently part of the three habitats in which the largest number and the most species of wildlife are observed. Indeed, the thought that "acorn production reigns supreme as the greatest contributor to the welfare of forest wildlife" (Shaw 1971) seems to be supported by this study.

Findings from this study, although preliminary, are the best available for the specific area, and have proved valuable for showing relative wildlife abundance in different oak-related habitats. They currently are being used to assess wildlife values on other possible conversion areas.

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Quercus agrifolia

Acorns—Food for Modern Man[1]

Jeanine A. Derby[2]

Abstract: Acorns, fruit of the oak, offer a nutritional potential which has long been overlooked. In bountiful years surplus acorns remain after wildlife needs are met and seed crops are accounted for. The surplus could serve as a supplement to human diets. Through sharing my own experiences with acorns as a food source, I hope to entice others to experiment.

We have learned at this symposium that the acorn is of nutritional value to wildlife. We also know that acorns provided the staple diet for indigenous cultures in California (Balls 1972, Bean and Saubel 1972). Therefore, we can assume a food value to modern man, even though precise nutritional data is meager. Acorns are reported to be high in magnesium, calcium and phosphorus (Crowhurst 1972). When compared to barley and wheat, acorns are slightly lower in carbohydrate and protein content but higher in fat and fiber content (Bean and Saubel 1972), and therefore have a higher caloric content per unit weight than grains. Acorns contain one disagreeable and potentially harmful ingredient, tannin, which has a bitter and astringent taste. Tannin, however, is easily leached out of the acorn.

Native Indian methods of grinding, leaching and drying acorn meal are well documented (Balls 1972, Bean and Saubel 1972). The traditional food product was an acorn pudding or mush, quite tasteless to modern palates. The preparation of acorns can be adapted to modern technology and the product, acorn meal, is quite versatile. To demonstrate, there are acorn cookies for you to sample after the program.

When acorns begin to fall, (usually in October), gather them as they drop from the trees. Float the acorns in water, discarding the floaters and keeping the sinkers. If the acorns will not be processed immediately, store them in a freezer. Cold storage halts the work of tiny larvae which are a natural part of the acorn ecosystem. Removing the outer leathery shell is the most tedious part of processing. Apply pressure with pliers, cracking only the outer shell, and then peel it away. Remove the brown skin from the nut if possible. If the skin clings tightly, submerge the shucked nuts in water for several hours, rolling them between the palms frequentl The skins will loosen and float to the surface. This skin is likely to be high in tannin content and the nuts will leach more rapidly if most of it is removed. The acorn nuts are next ground in a blender to desired fineness. Add nuts to the blender one cup at a time, with a few tablespoons of water. When several cups of acorn meal have accumulated, proceed with the leaching process.

Indians worked in bedrock mortars, ideally near a running stream. Acorns were submerged for leaching or water was poured through a finely woven basket containing the acorn meal. Searching through my house for the equivalent of a flowing stream, I turned to the plumbing system. A cloth bag of acorn meal was submerged in the toilet tank where each flushing renewed the fresh water flow and no water was wasted. Expect brown-colored water in the toilet bowl for a few days while the leaching progresses. When the water is clear, acorns can be removed from the tank and drained. The leaching process can be accelerated by pouring hot water frequently through acorns in a cloth lined colander. The key to any leaching metho is to continue until water passing through the acorn meal is perfectly clear. The time will vary depending upon the year and the kind of acorns used.

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[1] Presented at the Symposium on the Ecology, Management, and Utilization of California Oaks, Claremont, California, June 26-28, 1979.

[2] Forest Botanist, San Bernardino National Forest, Forest Service, U. S. Department of Agriculture, San Bernardino, California.

After leaching, the acorn meal must be drained well. It can be used immediately or dried and stored. Dry acorn meal on trays in a low oven (125° F) or leave them for a day or two in a gas oven with no heat other than the pilot light. Stir occasionally to hasten drying. Acorn meal can be sun dried but must be protected from birds and insects. After the meal is thoroughly dry, store it under refrigeration or in a freezer.

I have used several kinds of acorns successfully, including non-natives. Quercus ilex and Q. suber seem to have a higher tannin content than the native live oaks that I have tried. Quercus agrifolia, Q. chrysolepis and Q. kelloggii all seem equally good to my indiscriminate taste. Many sources report Q. kelloggii (California black oak) as a favored species among Southern California Indians.

I have substituted acorn meal for portions of the dry ingredients in breads, crackers and cookies. I find that substitution of acorn meal for up to one third of the flour called for in most recipes will not change the texture of the final product. Oatmeal cookie or muffin recipes are ideal for use with acorn meal. Just substitute acorns for one half of the oatmeal called for in the recipe. With a little experimentation, you too will find satisfaction and good nutrition from using acorns as a supplementary food source. Try it during years of plentiful harvest.

ACORN COOKIES

1 cup brown sugar
2/3 cup shortening
2 eggs
1 cup buttermilk
1 tsp. vanilla

2 cups flour
1/2 tsp nutmeg
1 tsp cinnamon
1 tsp baking powder
1 tsp soda
1/2 tsp salt

stir in last: 1 cup "quick" oatmeal
1 cup acorn meal

Cream sugar, shortening and eggs. Stir in vanilla, add buttermilk alternately with dry ingredients. Mix well. Stir in oatmeal and acorn meal. Drop teaspoonfuls onto greased baking sheet. Bake 12 minutes at 375° F.

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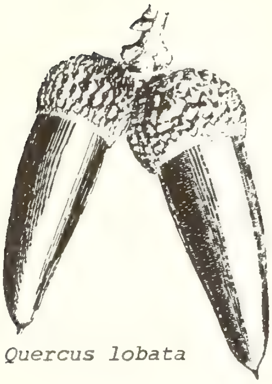
Quercus lobata

Wood Products from California Oaks, Cal Oak Lumber Company Style[1]

Guy Hall and Richard Allen[2]

Abstract: In 1965, Cal Oak Lumber Company, with $7,400 capitalization, began utilizing native California oaks as its basic raw material. The then-conventional sawmilling machinery and techniques proved inefficient, wasteful, and only moderately successful. This led to development of the mini-log and mini-mill concept which enabled the processing of a wide variety of hardwood logs, including those of small diameter and excessive crook. Higher utilization in woods and mill, and production of more high-grade material proved the efficacy of the concept. Wood products presently produced are high-grade lumber and pallets plus industrial timbers, sawdust for mulching, and bulk and prepackaged firewood. Cal Oak, as the largest hardwood manufacturer in California, has milled an estimated 70MM board feet of hardwood logs. This paper will primarily deal with the products manufactured from oak logs. Subjects deserving separate attention include hardwood lumber harvesting techniques and species characteristics.

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Several California oaks recently have become new and important wood product resources. Development of this resource has been continuous since 1965, largely through the cooperative efforts of Cal Oak Lumber Company, the University of California Forest Products Laboratory, the U.S. Forest Service, and others. As is true with most pioneering efforts, the path is seldom smooth. Many companies, large and small, have previously attempted the development and marketing of western hardwood lumber products. These authors know of no long-term survivors of these numerous attempts except Cal Oak Lumber Company, which unlike the others, depends entirely upon western hardwoods, chiefly oaks, for its raw material base. Over the years, Cal Oak has learned to deal with the relatively high susceptibility of western hardwoods to various types of deterioration during processing. Some of the categories of deterioration include: (a) fungi attacks which cause stain and discoloration of the finished product, (b) collapse and honeycomb during drying, (c) damage by insects (wood borers), (d) end and surface checking of boards, and (e) distortion and warping during drying. This is not to imply that Cal Oak has solved all the various problems of producing and marketing western hardwood products. Indeed, Cal Oak is in a state of continuous research and development, seeking new and better methods and products.

California black oak (Quercus kelloggii), and valley oak (Quercus lobata) are two major western hardwoods which have been developed to commercial sawtimber significance by Cal Oak Lumber Company, with California black oak comprising the bulk of production (fig. 1). Although this paper deals with California oaks, it should be noted that Cal Oak utilizes many other western hardwoods as well. Some of these include: tanoak (Lithocarpus densiflorus), Pacific madrone (Arbutus menziesii), California sycamore

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[1] Presented at the Symposium on Ecology, Management, and Utilization of California Oaks. Claremont, California. June 26-28, 1979.

[2] President and Chief Forester, Cal Oak Lumber Company, Oroville, California. Both are forestry graduates from U.C., Berkeley. Mr. Allen is presently employed by Siller Bros. of Yuba City, CA.

Figure 1--A typical deck of California black oak sawlogs at Cal Oak's mini-mill.

(Platanus racemosa), Fremont cottonwood (Populus fremontii), bigleaf maple (Acer macrophyllum), northern California walnut (Juglans hindsii), willow (Salix spp.), and others.

The commercial development of black oak has reversed previous thinking--the species is now viewed as a valuable resource. Not so long ago it was considered a "weed" and many thousands of dollars and millions of board feet were wasted through poisoning and girdling. Now it is regarded as an asset, creating jobs and incomes for primary industries (harvesting and sawmilling), and raw materials for many secondary manufacturing concerns (pallet manufacturers, cabinet and furniture manufacturers, etc.). An interesting project for an economist would be to quantify the dollar multiplier effect of this raw material. Conservatively, it is at least 10=1, which means that for every dollar spent by Cal Oak, ten dollars are generated into the nation's economy.

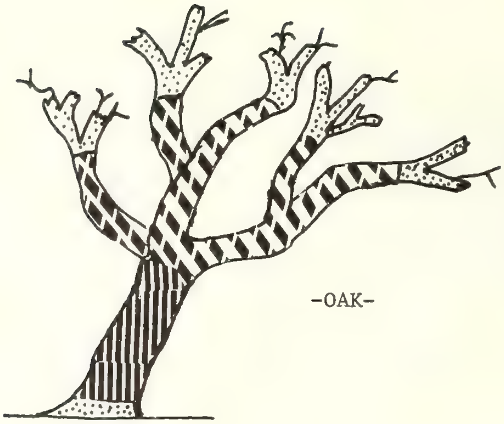
Cal Oak Lumber Company depends largely on California black oak for its raw material base. The wood structure characteristics of this oak are very similar to the Appalachian red oaks. One major difference is growth form. While many commercial eastern oaks produce much of their volume in relatively straight, main stems, a portion of older California black oak volume is found in limbs and branches. Tree trunks are not always straight either.

In its early years, Cal Oak operated a sawmilling operation using conventional mill equipment capable of utilizing only the branch-free straight main stems and occasionally some of the limb material which was of sufficient diameter and length to make a log 10 inches in diameter and 10 feet long. It soon became apparent that conventional mill equipment was wasteful and inefficient. Cal Oak simply was not able to utilize many otherwise sound trees due to crook and/or small diameters, nor was it able to utilize sound limbs and branches. An estimated 37 percent by weight of each tree was being left in the woods.

During 1972-74, Cal Oak designed and constructed an innovative new sawmill. In many respects it is like a conventional mill except that it is miniaturized to handle short logs from 3½ to 8 feet in length. Unlike a conventional bolt mill which also handles short lengths of small-diameter logs, Cal Oak's new mill is not limited to one or two dimensions all cut in one plane, nor is it limited to small diameters. By using a carriage and bandsaw headrig, it is capable of sawing logs from 7 to 48 inches in diameter. The headrig also gives the capability of turning each log 360 degrees around its longitudinal axis. Thus the new mill can cut many dimensions selectively for grade and produce lumber of better quality. Logs are sawn specifically to maximize the output of higher grade lumber, and by utilizing short logs, with defects cut out, to produce an abundance of 4 foot "clears". Although much shorter than the conventional 10 to 16 foot board lengths, these have been well accepted by many consumers. The innovation of this system of milling has, of course, created some disadvantages. Most notable is the restriction of lumber length with its associated higher production and handling costs, and a traditional buyer resistance. Nevertheless, advantages overly compensate for the disadvantages.

The capability of cutting shorter than conventional logs also allows utilization of material which by normal sawlog standards would be culled due to crook. Thus more wood is utilized and less is left in the woods. Because the short logs produced are not exactly "bolts" and not really "sawlogs", Cal Oak coined the term "mini-log" to describe them, and the term "mini-mill" to refer to the new mill.

The mini-mill allows Cal Oak to utilize many trees which formerly would not have been harvested, especially those having small diameters and crooked boles (fig. 2). The mini-mill also allows the utilization of limbs and branches, previously left in the woods as waste. Before the mini-mill, Cal Oak utilized only 50 percent by weight of a given tree. Now, it is utilizing about 87 percent by weight of the same type of tree. By combining the 37 percent additional utilization with another 25 to 50 percent additional volume (by weight) from a given stand of previously unmerchantable trees, the mini-mill has increased total utilization of hardwoods by 62 to 87 percent.



Vol. by % Wt.		
50%	▥	Conventional Sawlog
37%	▨	Additional Lumber Utilization by Mini-Mill
13%	░	Left in Woods, or Recovered as Firewood
100%		

From the 87% of the tree taken to the mini-mill, product recovery is approximately divided as follows:

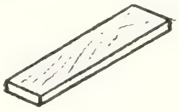
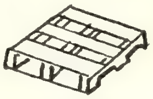
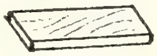
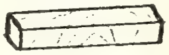
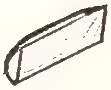
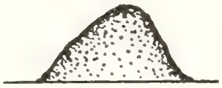
60%		Lumber & Shook, of which	33% is pallets	
			22% is cabinet, furniture, & paneling stock	
			5% is industrial timbers	
			60%	
20%		Slabs & Edgings, of which	10% is boxed as market firewood	
			7% is sold as bulk firewood	
			3% is wasted	
			20%	
20%		Sawdust & Shavings of which	17% is sold as mulch, etc.	
			3% is wasted	
			20%	
		TOTAL	100%	

Figure 2--Western hardwood utilization, mini- mill style 1978, by Cal Oak Lumber Co., Oroville, California.

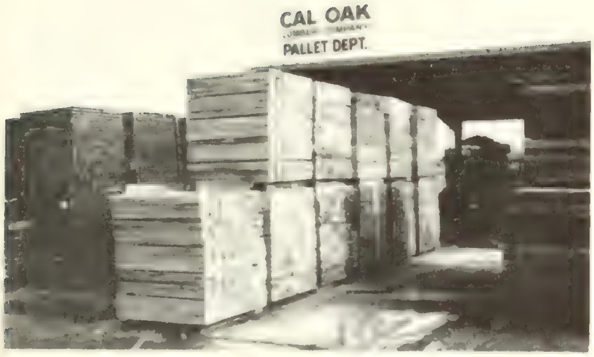


Figure 3--Pallet shook produced at Cal Oaks mini-mill stacked and waiting for manufacture into pallets.

Most important is that the mini-mill can now produce a significant "overrun" from very difficult logs.

Logs for the mill are purchased on a weight basis with the price per ton varying with grade. The conversion from ton to board feet is about 6.5 to 1. The logs are trimmed, conveyed to the mill and there reduced to short lengths. About 300 to 400 such short logs are sawn in each 8-hour shift, with two shifts usually operating. The total for two shifts is about 25,000 board feet per day, plus 15 to 20 cords of firewood. Yearly production from the mill is about 6 million board feet plus the firewood.

By producing short pieces of precise length, width, and presurfaced thickness, the mini-mill produces pallet shook ready for assembly into pallets (fig. 3). This process alone has eliminated the need for a planing and cut-up process whereby certain desired grades are sized and precision-trimmed from longer lumber. Thus the mini-mill has eliminated the cut-up process, which wasted 20 to 25 percent of the limbs, and now produces graded pallet shook ready for assembly into highgrade pallets. Of course, the high cost of machining associated with the cut-up process also was eliminated. Seven workers are required to operate the "floor" of the mill. Additional personnel for the second shift, for yard, shipping, remanufacture, sales, forestry and overhead bring total employment to about sixty workers.

As shown in figure 2, most of an oak tree is utilized. On a weight basis, Cal Oak's products can be divided into three major categories:

Lumber and shook	60 percent
Slabs and edgings	20 percent
Sawdust and shavings	20 percent

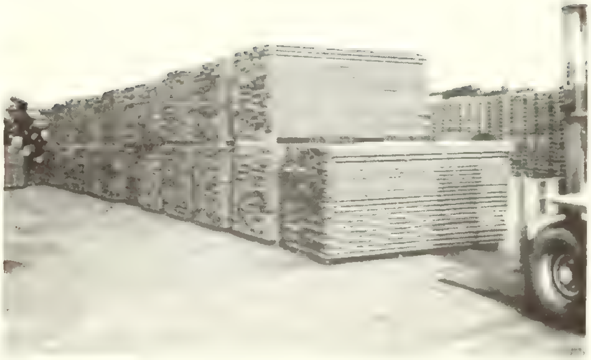


Figure 4--Upper grade oak lumber air drying in preparation for kiln curing.

Figure 5--Cabinet door panels made of upper grade oak are used in high quality kitchen cabinets.

About 60 percent by weight of Cal Oak's mill production is lumber. Of this 60 percent, slightly over one third is recovered as "upper grade" material. After sawing, the boards are carefully piled to permit good air circulation (fig. 4). Boards are air dried for three to eight months, depending on weather, to bring the moisture content down to 24% or less. Ends of the boards have been waxed to avoid checking. They are then placed in a dry kiln for further seasoning. This upper grade material is sold primarily for use in cabinets (fig. 5), paneling and moulding (fig. 6), and furniture (fig. 7).

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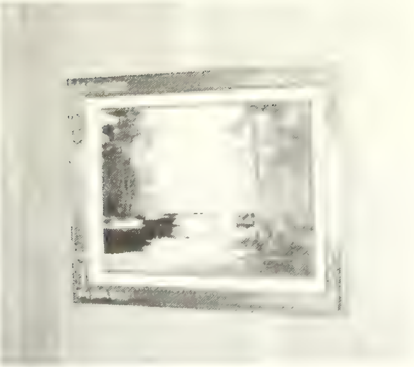

Figure 6--Upper grade oak is used for molding stock, picture frames and other specialty items.

Figure 7--Two typical oak products, a solid oak table and oak panelling on the wall behind it.

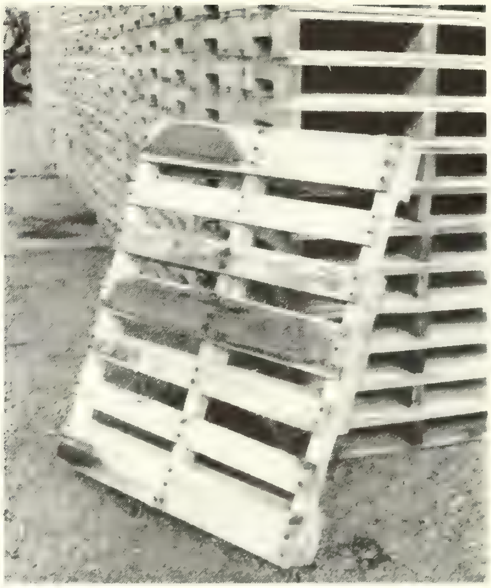

Figure 8--A finished oak pallet ready for shipment.

The short "clears" mentioned earlier fit well into the manufacture of most of these products. The remaining two thirds of the lumber produced is lower grade. Most of this balance is utilized at Cal Oak's pallet plant, or sold as pallet shook to other assembly plants. The pallet operation works in conjunction with the mini-mill.

Most people do not realize the importance of pallets in our society. Of all the uses of wood, pallets rank second in the United States. Fully 15 percent of all wood goes into pallets. Pallets from oak are considered the "Cadillac" of such structures (fig. 8). They have to be able to stand up to heavy loadings and last for about 4 years. Or, stated differently, oak pallets have a life expectancy of 70 uses as compared to a single use for some pallets.

At Cal Oak, the pallet line includes an automatic stacker and other sophisticated machinery to facilitate pallet assembly. A pallet line costs about $150,000. Four workers will put up 1200 pallets in an 8-hour shift. Each pallet presently sells for about $10.00, and most go to grocery chains.

Slightly over 10 percent of the lower grade is produced as short industrial timbers and blocking (fig. 9). Examples of their uses

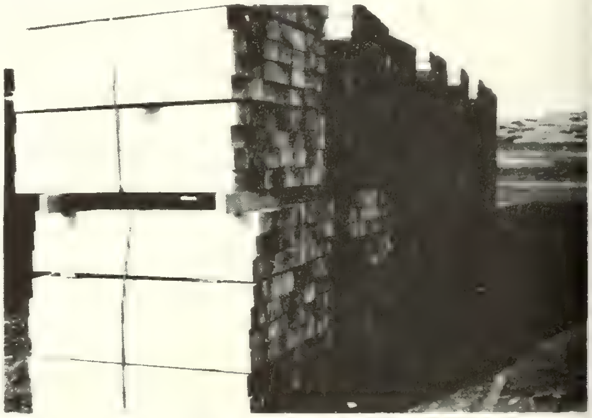

Figure 9--Lower grade oak is cut into short 4 x 6 x 48 inch industrial timbers.

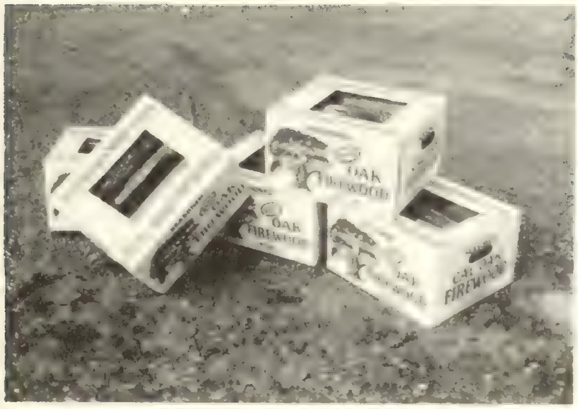

Figure 10--Oak slab firewood (dried, fumigated, and shrink-wrapped in plastic) is packed in 1 cubic foot boxes for retail sale in food markets.

have been in the construction of dock facilities overseas and tunnels of the Bay Area Rapid Transit System.

Merchandising oak firewood has taken some effort. Consumers want a clean, dry, insect-free product with high heat energy. Wood borers often infest dry oak and it is disconcerting to consumers to have the larvae, which resemble small worms, come out of the firewood and crawl around the room. The homeowner's next thought is that the borers will soon be boring in the walls of his house. At Cal Oak the wood is dried, dust and dirt blown off, fumigated, shrink-wrapped in plastic, and stacked in cubic-foot boxes (fig. 10).

About half of the firewood produced by Cal Oak is sold in these boxes to large grocery concerns for retail sale. Naturally, the boxes are shipped on Cal Oak pallets. About 35 percent of the firewood is sold at the mill directly to local consumers, usually in pickup-load quantities. Some $75,000 of such wood is sold annually. About 15 percent of the firewood ends up as waste, but this percentage is decreasing as home heating costs increase.

The remaining 29 percent by weight of mill production is in sawdust and shavings (fig. 11). Over 85 percent of this is either sold or given away as mulch, livestock bedding, or other uses. About 15 percent is waste.

Other wood products from California oaks include split and round firewood produced from forest log residue and reject logs at the mill (as opposed to that produced from mill residue). After logging, parts of each tree remain which are too small, rotten, or crooked even for the mini-mill. Some of it can be used for firewood. Cal Oak logging crews work closely with firewood cutters. The cutters take the wood and Cal Oak has less slash to clean up. Burls and twisted-grain slabs of oak are utilized for clocks, tables, plaques, and novelties. Oak burls can be truly beautiful (fig. 12) and good ones are expensive.

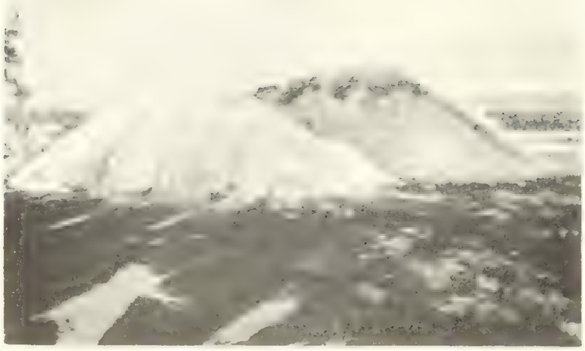

Figure 11--Twenty percent by weight of the Cal Oak mill production is in sawdust and shavings.

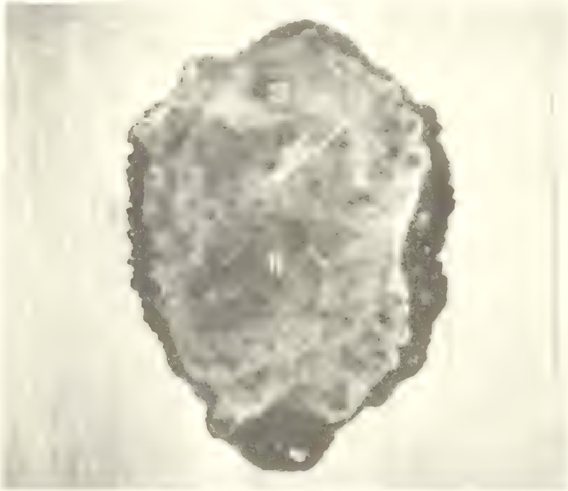

Figure 12--Oak burls can be made into attractive wall clocks.

California black oak, being a vigorous stump-sprouter and periodically a prolific acorn producer, regenerates naturally especially in areas of commercial harvest. This natural regeneration, in addition to the large volume of smaller, not-yet harvestable stems, which will reach commercial size over the next one or more decades, and a significant volume of currently merchantable oak (supplemented by other hardwoods), gives futurity to Cal Oak's operations. It also warrants Cal Oak's continued sophistication of its product line. Remanufacturing technology and more and better by-product utilization show particular promise. This means that Cal Oak (and any others who enter the western hardwood business) will have to continue to meet the unique challenges presented by California hardwoods. These challenges occur in such areas as stem form, light stand density, environmental considerations, harvesting, transportation, market peculiarities and limitations, and by-product utilization.

It is not enough that Cal Oak alone has successfully established a short, multi-diamete log milling facility; precision-sized shook production direct from the sawmill; short-length upper-grade lumber acceptance; and the first waste-derived grocery shelf oak firewood product acceptable in volume material handling. To continue its success at manufacturing and marketing native California hardwoods, Cal Oak must continue to research and implement new and better ideas to successfully compete in tomorrow's markets.

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U.S.GPO:1981-790-351/149

Plumb, Timothy R., technical coordinator.
1980. **Proceedings of the symposium on the ecology, management, and utilization of California oaks, June 26-28, 1979, Claremont, California.** Gen. Tech. Rep. PSW-44, 368 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

The symposium, held at Scripps College in Southern California, addressed most aspects of California's vast oak resource. Papers represented four major subject categories: ecological relationships, silviculture and management, damage factors, and products. Both scientific and applied information was presented, including original material not published previously. Individual topics ranged from taxonomy and historical relationships to management of insects and diseases, and various oak products. In California, oaks' value for wildlife, recreation, watershed protection, and esthetics exceeds their value for traditional lumber and wood products.

Retrieval Terms: Quercus spp., California, ecology, silviculture, forest management, forest protection

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A Vegetation Classification System Applied to Southern California

Timothy E. Paysen Jeanine A. Derby Hugh Black Jr. Vernon C. Bleich John W. Mincks

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CHAPARRAL

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Acknowledgments:

In 1977, the Forest Service, U.S. Department of Agriculture, established a research and development program at this Station titled "Vegetation Management Alternatives for Chaparral and Related Ecosystems." This 5-year program, with headquarters at Riverside, California, is an intensive effort to develop, test, and demonstrate a wide range of operations for maintaining or increasing the productivity of chaparral and related ecosystems in southern California.

Work toward the development of the Vegetation Classification System described in this report was facilitated through the efforts of many persons. Ike Parker, ecologist, Tahoe National Forest, Forest Service, U.S. Department of Agriculture, made available the experience he obtained while working on the Forest Service's Pacific Southwest Region (R-5) pilot ecology program. William Harvey, range conservationist, Inyo National Forest, served as an advisor in matters pertaining to range management during the initial development of the system. Mona Myatt and Terry Yonkers, both ecologists, of the Southern California Edison Company, were a source of valuable advice, and graciously provided plant community information from their Coastal Resources Inventory. Constructive comments based on field tests of the system were received from Waldo Burford and John Sully, biologists, both of the California Department of Transportation; Jan Zabriskie of the University of California, Riverside, Deep Canyon Desert Research Station; and Bruce Smith, Maureen Hales, and John Hall, biologists, all of the Riverside office, Bureau of Land Management, U.S. Department of Interior.

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CONTENTS

Introduction 1

System Overview 2

- Regionalization 2
- Application 3

Classification System 4

- Association 5
- Series 5
- Subformation 5
- Formation 5
- Phase 5

Nomenclature 6

Field Key to Subformations 9

Series Descriptions 12

- Closed Forest Formation 12
- Woodland Formation 15
- Shrub Formation 18
- Dwarf Shrub Formation 24
- Herbaceous Formation 25

Appendix 29

- A. Climate Regions of Southern California 29
- B. Species Index 29
- C. Glossary 32

Literature Cited 33

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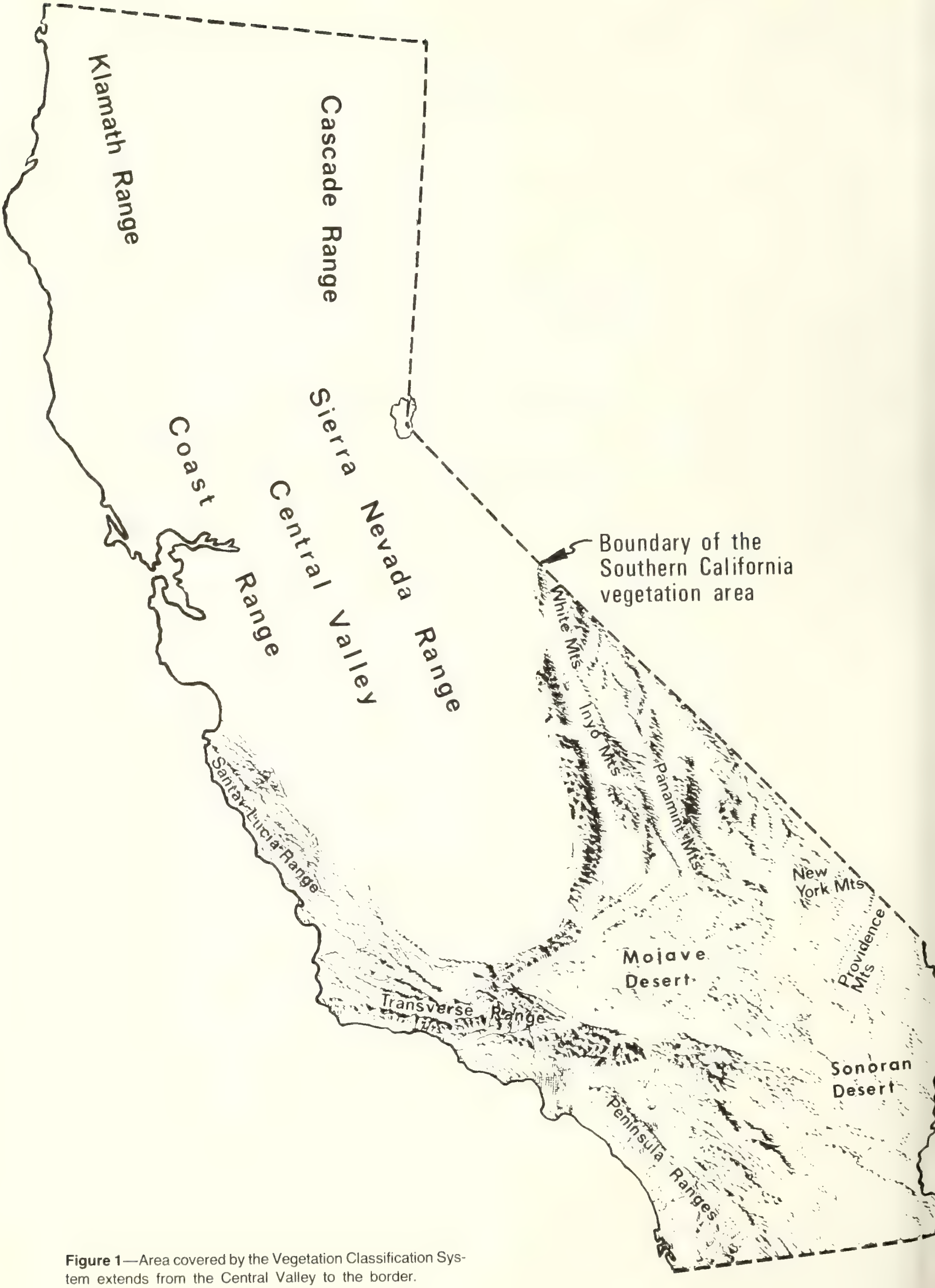

Figure 1—Area covered by the Vegetation Classification System extends from the Central Valley to the border.

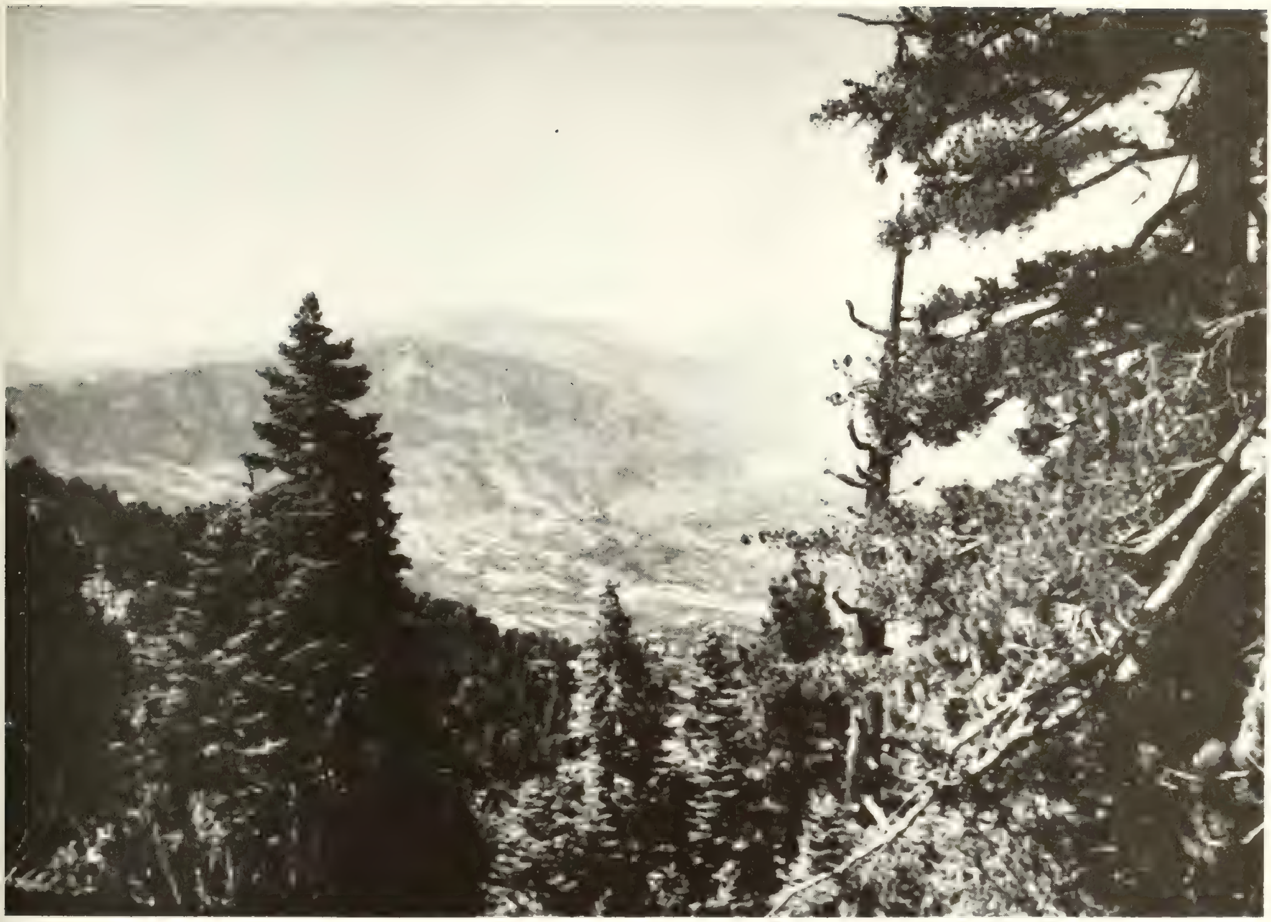

Figure 2—Elements of the Conifer Forest Subformation in southern California contrast sharply with the mosaic of Chaparral and Soft Chaparral Subformations seen in the background. The conifers nearly hide the smog in the valley bottom.

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The classification system that was developed is hierarchical, in five levels of descriptive detail. It was designed to accommodate the kinds of information needed for management decisions at the project level or at the broad planning level.

The System shows categories of vegetation as they now exist in southern California. In time, these categories will be updated in order to keep the list of recognized Series relevant. The basic framework of the System allows vegetation

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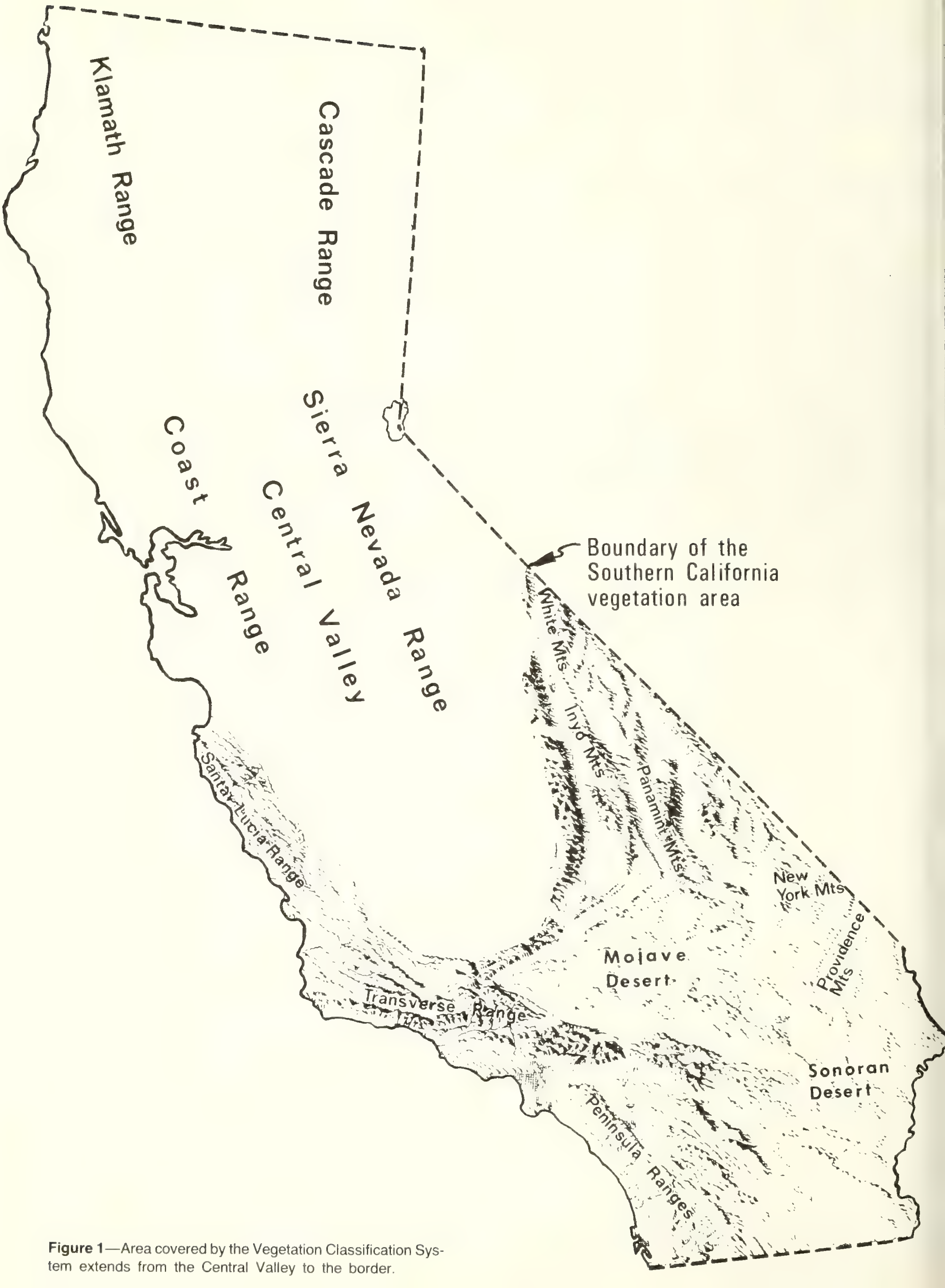

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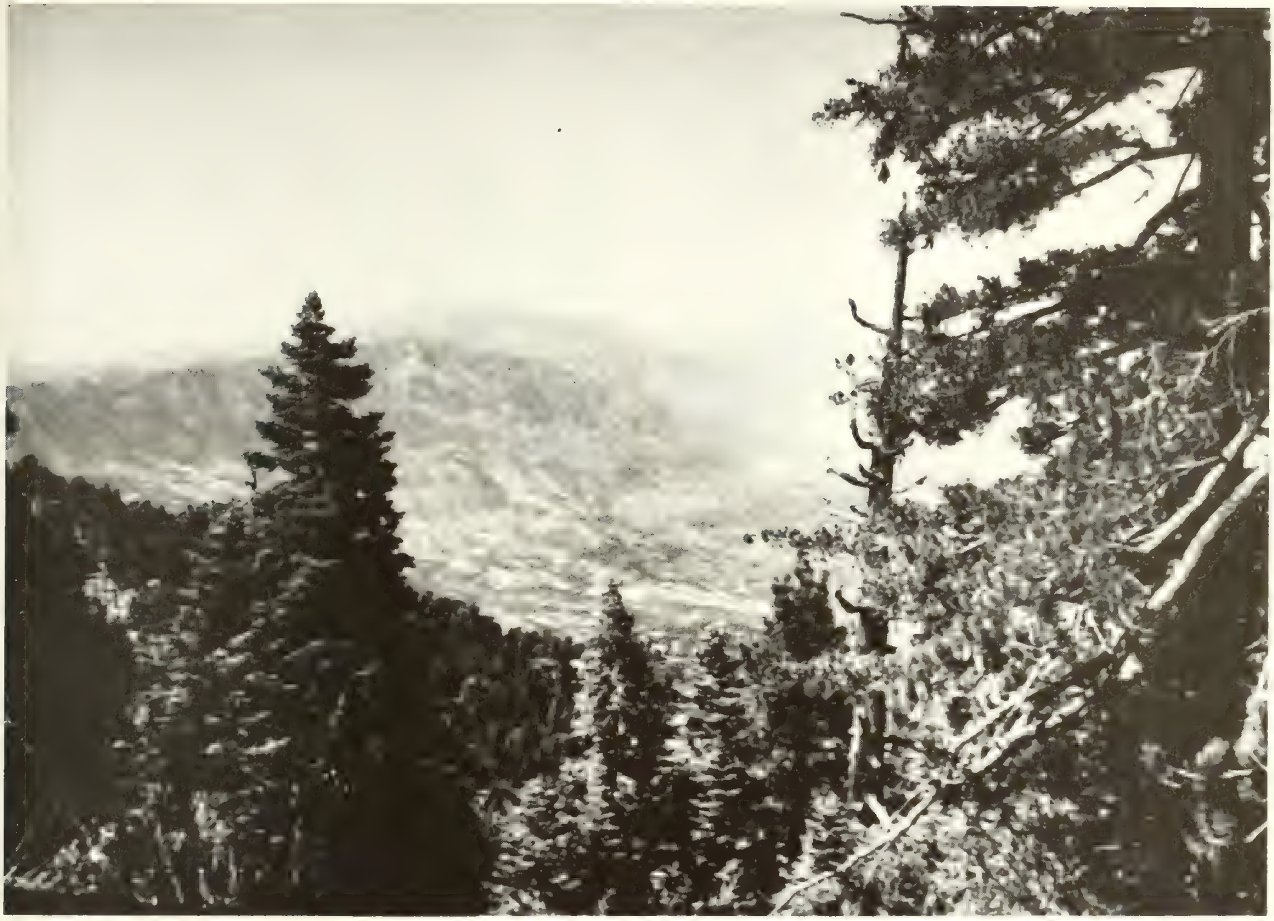

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categories to be added or deleted at any level of the hierarchy in order to reflect new information. Although agencies and functions may need to extend or build upon the existing classification, a uniform terminology can be maintained.

SYSTEM OVERVIEW

Development of the Vegetation Classification System for Southern California began with a review of existing systems (Browne and Lowe 1974, Cheatham and Haller,[2] Driscoll and others,[3] Kuchler 1964, Mueller-Dombois and Ellenburg 1974, Munz 1973, Thorne 1976). The range and distribution of vegetation series were determined through literature review (Munz 1973, 1974; Critchfield 1971; Griffin and Critchfield 1972; Horton 1960; Shreve and Wiggins 1964; McMinn 1939; and Latting 1976), through personal contact with many specialists throughout central and southern California, and from our field experience. This Classification System is broadly patterned after an outlined system proposed by Leven and Horton.[4]

The Vegetation Classification System for Southern California is compatible at all levels with a national land classification system being proposed by the Forest Service[3] and which incorporates the international system for classifying vegetation (UNESCO 1973). The System is based upon a hierarchical stratification of plant cover as described below.

The *Formation* is the uppermost level in the hierarchy, and its elements are defined according to physiognomic criteria. A given Formation is an aggregate of individual plant communities with the *same* physiognomy or stand structure. A broad unit of vegetation that is a mosaic of different physiognomic types, but is predominantly made up of one physiognomic type, such as closed forest, is not itself a Formation. It is an aggregation of various Formations, each of which corresponds to a distinct physiognomic type within the mosaic (*fig. 3*). Example: An annual grass community is considered a member of the Herbaceous Formation, even though it may occur in an area that is generally dominated by stands of conifers (*figs. 4, 5*). Within a given Formation, plant communities with dominant species that have the same general leaf and stem morphology characteristics are grouped into a *Subformation*. The Closed Forest Formation is therefore composed of the Conifer and Broadleaf Subformations.

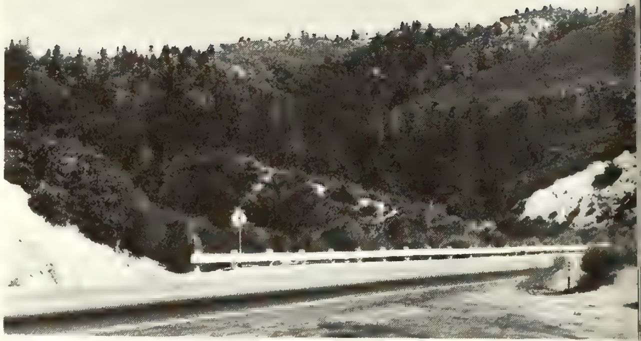

Figure 3—Disturbance by fire has resulted in this complex of C
Forest and Shrub Formations.

The *Series* and *Association* are taxonomic units. These tw
categories address specific plant communities. Together the
form the heart of the Classification System. The *Series* is
generalization of Associations with the same dominant ove
story. The *Association* is the basic unit of the Classificatio
System. An Association is a plant community, growin
under uniform environmental conditions, with a particul
dominant overstory species, and characteristic associate
species. The nomenclature for Association reflects the dom
nant species, and the most prevalent (or distinguishing) ass
ciated species. The latter is most often an understory specie
but can be an associated overstory species. Examples: Pinyo
pine/mountain mahogany/phlox or interior live oak/mar
zanita/needlegrass.

The *Phase* is a category that allows us to deal with th
variability that must exist within given associations (*fig. 6*
It can be used to specify growth stages or condition of veget
tion, or it can be used to describe a particular realization
the Association that has an especially noteworth
character—such as a stand (or portion of a stand) with
particularly dense overstory.

The Associations have not yet been developed. They ca
be identified on the ground on a project basis or identifie
uniformly for the entire southern California area aft
adequate field samples are taken.

Regionalization

It is often useful to regionalize a classification system if
covers a large geographic area, or if it covers an extremel
diverse environment. This kind of stratification assists th
user by eliminating ambiguities that must exist in an exte
sive system. It provides a sorting process that facilitat
practical application. To this end, we are suggesting the us
of climate regions, according to descriptions adapted fro
Almquist.[5] While these climate regions do not represe

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[2] Cheatham, Norden H., and Robert Haller. University of California natural land and water reserves system, an annotated list of California habitat types. (Manuscript in preparation.)

[3] Driscoll, Richard S., John W. Russell, and Marv C. Meier. Recommended national land classification system for renewable resource assessments. (Report on file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.)

[4] Leven, Andrew A., and Lowell E. Horton. 1976. Inventory of ecological land units, resource analysis units, and management units. *In* Land use planning training test materials. (Report on file at Pacific Southwest Region (R-5), Forest Serv., U.S. Dep. Agric., San Francisco, Calif.)

[5] Almquist, G.L. 1977. Macroclimatic regions of Southern Californi
(Report on file at the Forest Fire Laboratory, Pacific Southwest Forest a
Range Experiment Station, Riverside, Calif.)

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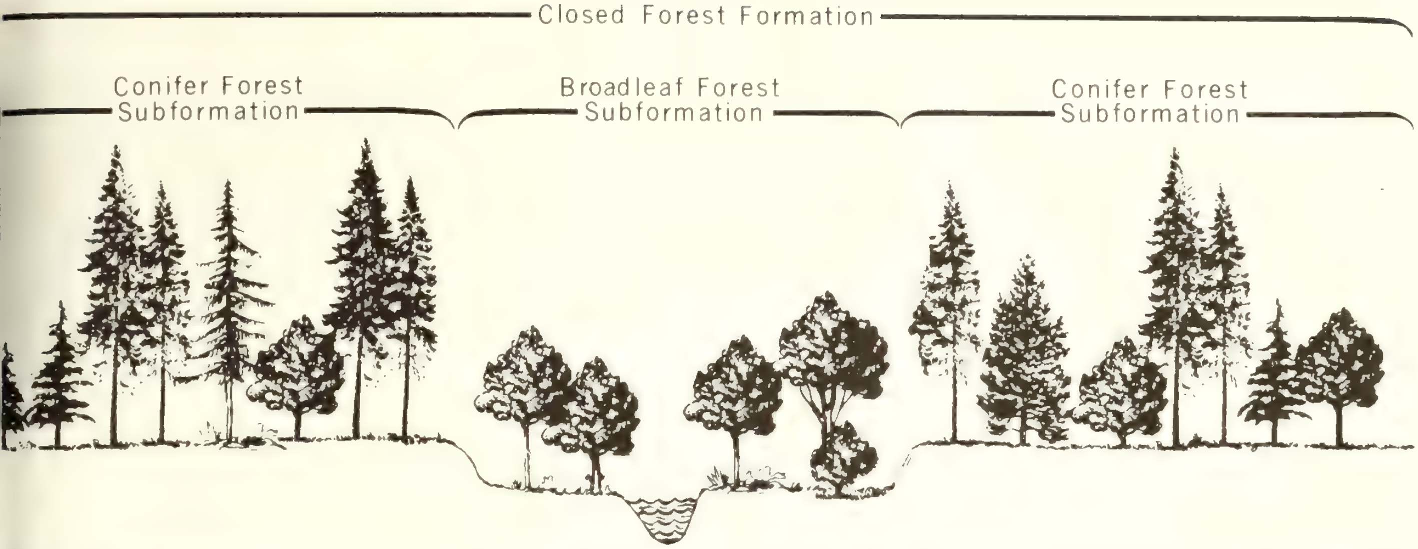
Closed Forest Formation
Conifer Forest Subformation
Broadleaf Forest Subformation
Conifer Forest Subformation

ure 4—This "typical conifer forest" is, in fact, a complex of two distinct Subformations: the Conifer Forest Subformation and the Broadleaf Forest
ıformation.

ividual strata that are unique in a geographic sense, they
provide a set of environmental strata that are useful de-
iptive qualifiers. Example: The Montane region exists in a
nber of places in southern California; nevertheless, it is
ful to distinguish elements of the Canyon Live Oak Series
t exist in a Montane region from those that exist in an
erior Valley region.

\ number of climatic and geophysical variables affect
etative growth, reproduction, and distribution. Some of
variables include temperature, precipitation, and relative
nidity, along with the seasonal distribution of these fac-
s; dominant wind patterns; orographic influence; and prox-
ty to major land mass changes. It is difficult to define all
hese interactions with geographic and elevational bound-
es, particularly in an area of great diversity such as south-
California. The adaptation of Almquist's descriptions
ves for the present as a regionalization of the southern
ifornia vegetation area. It may someday be supplanted by
ıore general regionalizing system, or it may remain as a
al subregionalization of one of these systems.

/egetation distribution relative to climate regions is
sented in a table of the Series, along with the Field Key,
ow. The Appendix contains descriptions of each region.

pplication

The Vegetation Classification System for Southern Cali-
nia can be used to describe environmental settings, to
ıvide a basic framework for vegetation mapping, and to
alify map class descriptions. It can also serve as the com-
n link between functional or technical classification sys-
ns, thereby facilitating communication between disci-
nes.

The System will become most meaningful to land mana-
s when Associations are identified for southern California
etation. Significant Associations can be identified only

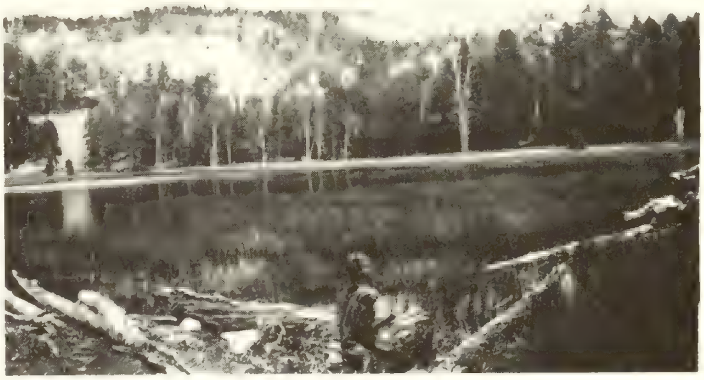

Figure 5—The Herbaceous Formation is represented in the middle foreground by an element of the Sedge Series, and in the meadow in the left middle ground by the Forb Series. The Lodgepole Pine Series represents the Closed Forest Formation in the middle ground and on the hill in the background, and the Dwarf Shrub Formation fills in the remainder of the hill that is devoid of lodgepole pine.

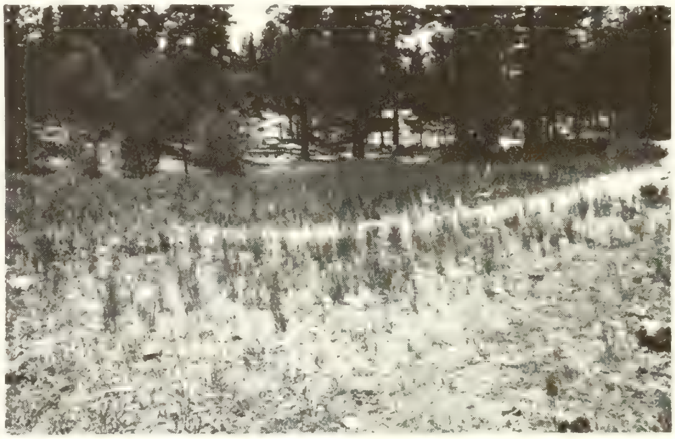

Figure 6—Two Phases of the Forb Series are evident in the foreground: The extreme foreground shows an early successional Phase resulting from equestrian overuse; the middle foreground contains a mature Phase of the Series.

after careful evaluation of plant distribution patterns and their associated environmental settings. Resource managers and researchers should work together in this process.

When Associations are identified, their successional status should eventually be determined. Knowledge of the potential inherent in a plant community has practical application in local resource management. It can also facilitate response to shifts in management direction from the national level. For example, an increased emphasis on managing forests and woodlands for recreation, wildlife, and energy production may bring about a response to increase production of oaks in southern California. Knowledge of sites that have potential for high oak productivity on an extended basis will eliminate fruitless attempts at oak management on marginal oak sites.

CLASSIFICATION SYSTEM

This hierarchical stratification (*fig. 7*) has been designed to describe existing vegetation—the dominant and associated vegetation which presently occupies the site. However, because the System is descriptive and is based upon stand physiognomy and floristics, it can also be used to describe potential vegetation—which is simply the "present vegetation" of some future time.

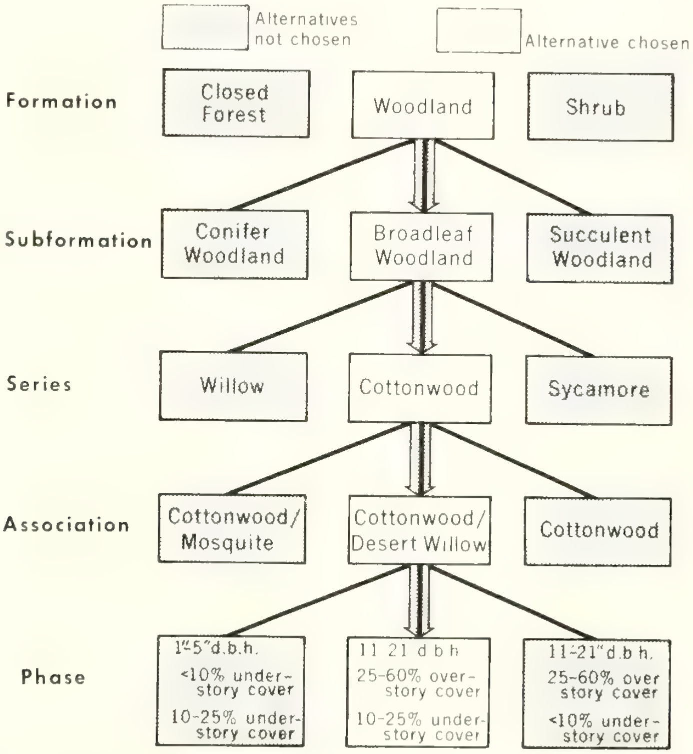

Figure 7—The hierarchy of the Vegetation Classification System as applied to southern California is shown here in an example. In the diagram, the classification of a stand becomes progressively more precise as it moves through the levels recognized in the classification (Formation, Subformation, and Series). The most specific level is the plant community (Association). Finally, the appropriate descriptive Phases are determined and the proper alternatives are chosen.

Perhaps the easiest way to understand the relationsh between the various levels of the System is to start with basic unit, the Association, and work up the hierarchy fro it. The System is an aggregating system from the Associati up through the Formation. In an aggregating (or agglomer tive) system, the classes at a given level in the hierarchy a grouped, according to prescribed similarities, to form class of the next higher hierarchal level. The Phase category, o the other hand, subdivides the classes to which it applied—this means that predetermined classes have bee generated, and are each to be subdivided on the basis internal differences. See the paper by Bailey and othe (1978) for a discussion of aggregative and subdivisive sy tems; the same concepts are discussed as agglomerative a divisive systems by Sneath and Sokal (1973) and by Piel (1969). Logically, the Phase level of description could applied anywhere in the hierarchy, since Series, Subform tion, and Formation are simply generalizations of the Ass ciation concept.

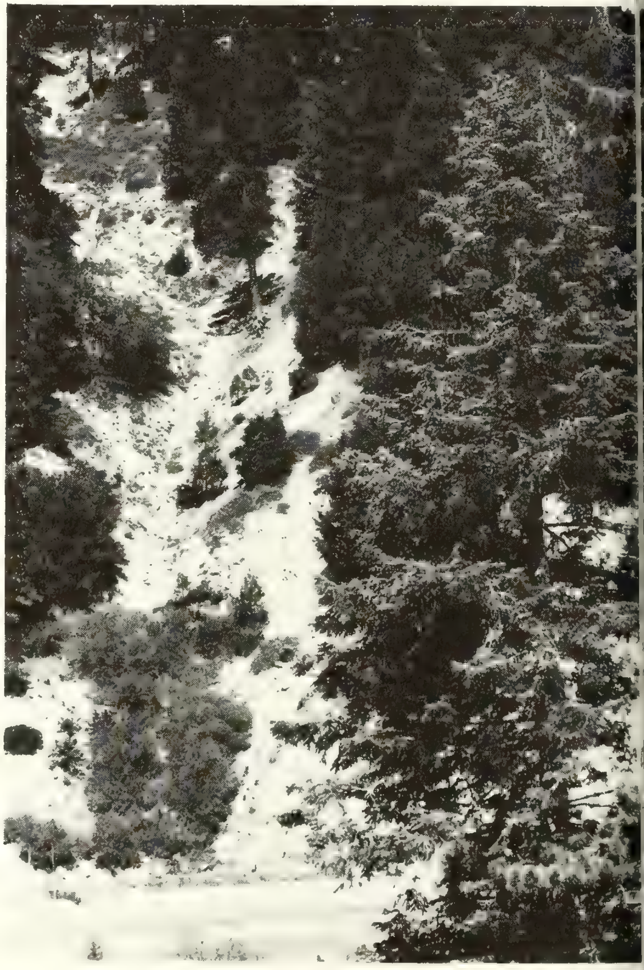

Figure 8—A natural habitat modification, such as a landslide, may resi in an Association that is distinct from the surrounding elements of th Mixed Conifer Series.

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ssociation

\ plant Association is an assemblage of plants, with a racteristic floristic composition, that occurs under a unim set of environmental conditions. This is the "standard" inition of a plant community (Ecological Society of ıerica,[6] Schwartz and others 1976). Unfortunately, it is hly ambiguous. The meaning of a "uniform set of ironmental conditions" is largely a function of the scale lescription being addressed by the Classification System lf. To define precisely the scale of description for this (or) classification system may not be entirely possible; this blem is dealt with in some depth in a forthcoming paper.[1] the purpose of this presentation, a rule of thumb will ve under most situations: A plant Association is recognize on the ground; the size of the unit may vary, but the ociation *almost always* has single species dominance in overstory. Exceptions to this rule will probably be rare. ield reconnaissance will be required to identify Associas. Individual Associations may exist as a result of interacs between "constant" environmental characteristics, predictable natural forces (*fig. 8*), and human influences. ough not necessarily permanent, a plant Association must ufficiently long-lasting to affect management policy. For mple, different environmental factors and different geographic history may determine that a stand of white fir he New York Mountains (Mojave Desert) and another in San Jacinto Mountains (Peninsular Ranges) represent ferent Associations within the White Fir Series. Similarly, ironmental and human factors may determine that adjat manzanita stands on the coast side of the San Bernardino untains represent different Associations.

ries

Series simply generalize plant Associations. All plant Asiations with a given dominant overstory species constitute eries that is named by that species. This category does not ɔly greater heterogeneity than the Association. It still ognizes the basic plant community, but does so at a genl level. It also allows for reference to an entire set of ristically related communities. Example: A particular nt community may be recognized as an Interior Live k/Eastwood Manzanita Association, or it may be recoged as an element of the Interior Live Oak Series. The basic t of precision—the plant community—has not changed, y the level of precision used to address it has changed.

ıbformation

\ Subformation is an aggregation of Series with a given siognomic character, and a particular stem and leaf rphology in the dominant overstory species. This category is included in the System to provide a set of classes that are more distinct than those at the Formation level. Reference will probably be made to this level more often than any other in the System, because the distinctions that it makes relate to common generalized references to vegetation. Example: Conifer versus broadleaf forests; chaparral versus soft chaparral.

Formation

A Formation is an aggregation of Subformations with a given physiognomic character. Example: All Subformations that are characterized by an overstory of trees with a closed canopy (60 to 100 percent crown cover) make up the Closed Forest Formation. Five Formations are currently recognized in southern California.

Phase

Although Phase is treated as a category of the classification, it is primarily a vehicle for management application of the System. It is a means of addressing variability within a plant community, and therefore only the general pattern of its use can be prescribed—strict definition of all potentially relevant Phases of plant communities is not practical. For each Formation described, we have suggested some possible terms that might be generally useful to describe the kinds of variations that are included in the concept of Phase. Many other such descriptors could be used in an actual inventory of vegetation.

Phase descriptors are often chosen in relation to specific functional applications. A silviculturist may define Phases of a plant community as different stand aggregations that call for different silvicultural prescriptions. In this light, a small cluster of a given species within a community constitutes a Phase of that community. At a different level, the silviculturist may view an age class within a plant community as defining a unique Phase. Similarly, a fuels specialist may be concerned with various characteristics of a chaparral stand, such as age, species composition, and vigor. A fuels specialist would therefore choose age, vigor, and probably mortality as elements for defining Phase categories. For different reasons, a wildlife biologist may recognize the same categories as the fuels specialist.

Outside the realm of pure classification, the Phase category is also a logical means for describing certain stages of succession. Depending upon circumstances, such as management goals or constraints, a plant assemblage may be viewed as in an early stage of development of one Association or an advanced stage of development for another Association (*fig. 9*). For example, a recently burned chaparral stand bears little resemblance to chaparral. The burned site is often dominated by elements of the Herbaceous Formation. Yet, knowledge of the chaparral successional cycle tells us that, if chaparral seedlings and sprouts are present, the recent burn is a *potential* chaparral stand in a pioneer stage—and contains a particular Phase of a potential chaparral Associa-

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Ecological Society of America. 1952. Report of the Committee on ıenclature. (Report on file at Ecological Society of America and Duke versity Press, Durham, N.C.)

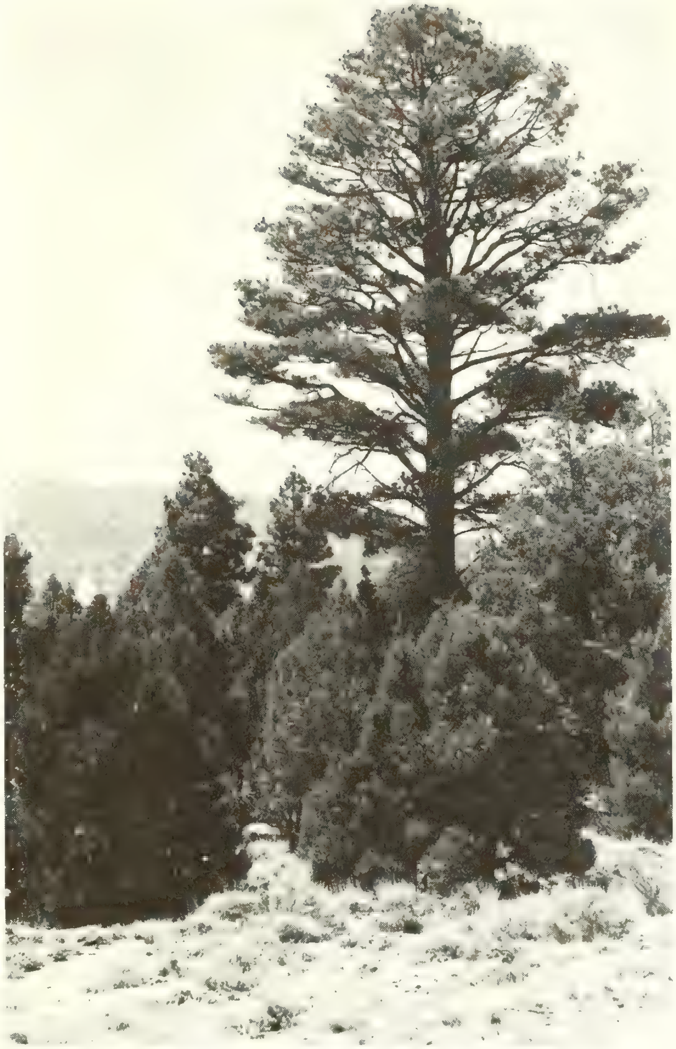


Figure 9—This Jeffrey Pine/Pinyon Pine/Sagebrush Association will, at some future date, become a Pinyon Pine/Sagebrush Association. The pinyon pine union represents a pioneer Phase of the potential Pinyon Pine/Sagebrush Association.

tion. This same logic can be applied to clearcuts in which the conifer reproduction has not yet attained dominant overstory status; a potential conifer stand exists and is described as being in a seedling Phase. We cannot, however, describe a bare granite slab as a pioneer Phase of a White Fir Association, even though we may be clever enough to trace community development forward to the potential existence of a stand of white fir. White fir seedlings must be clearly established in a pioneer Phase of a White Fir Association.

In using the Phase category for description of ecological stages, we are viewing the site in the context of what we know will probably happen, in order to classify it more usefully for our needs. The system itself does not tell us anything about succession; it simply allows us to take ecological development and succession into consideration in our classification. In *figure 10*, the development of one Association within another is diagrammed. The bottom strip shows how we might classify the site over the course of its probable future development. By establishing a sequence of Phases in this way, we provide a guide to classification of other sites representing different coexisting stages of development.

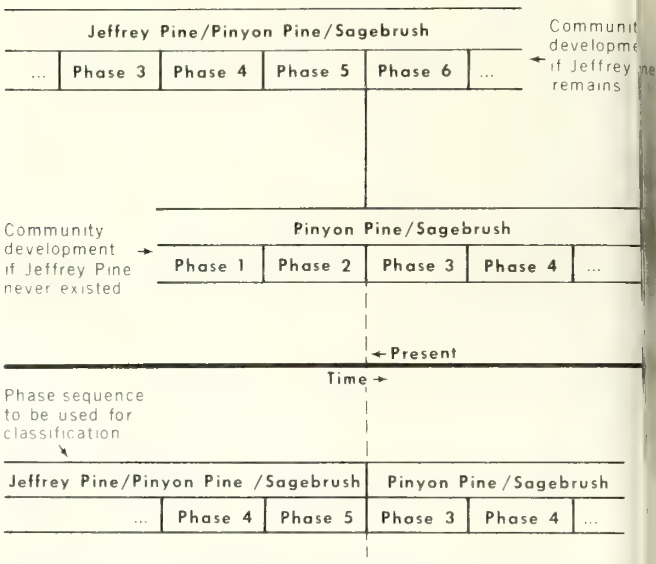

Jeffrey Pine/Pinyon Pine/Sagebrush
... Phase 3 Phase 4 Phase 5 Phase 6 ...
Communit
developme
if Jeffrey
remains
Community development if Jeffrey Pine never existed
Pinyon Pine/Sagebrush
Phase 1 Phase 2 Phase 3 Phase 4 ...
Present
Time
Phase sequence to be used for classification
Jeffrey Pine/Pinyon Pine /Sagebrush
... Phase 4 Phase 5
Pinyon Pine /Sagebrush
Phase 3 Phase 4 ...

Figure 10—The Phase category may be used to describe the ecologi stage of the stand in *figure 9.* The two upper strips show the devopmental phase sequences from which the bottom strip—a successio sequence moving from Jeffrey pine dominance to pinyon pi dominance—is derived. The basis for this is that the Pinyon pi Sagebrush Association was present, though "hidden" in the Jeff pine/Pinyon pine/Sagebrush Association. Thus, when it emerges, it already in the third phase.

Further discussion regarding this aspect of Phase, th means by which we may classify vegetation for a particula point in time and concurrently focus on the entire suc cessional spectrum of a vegetation community, is included i the paper mentioned earlier.[1]

To describe complex Phase categories, such as those tha we have suggested, a Phase code or index can be derived o the basis of the elements used to define the Phase categories For example, the Phases suggested for the Closed Fores Formation are based upon six diameter at breast heigh (d.b.h.) size class ranges, three overstory cover ranges, an three understory cover ranges. A stand with trees in th second size class range (1 to 5 inches d.b.h.), that is in th first overstory cover category (less than 40 percent), and i the third understory cover category (greater than 70 percent) would have a Phase Code of 2-1-3. The use of a Phase code i not mandatory, but it can be useful for data recording purposes.

NOMENCLATURE

The name given to an Association should indicate the dominant species and the dominant associated species. The combination of dominant and associated species should reflect the entire character of the Association—to the degree possible when using only a few species names. The following examples will illustrate the naming technique, and provide some rules of thumb.

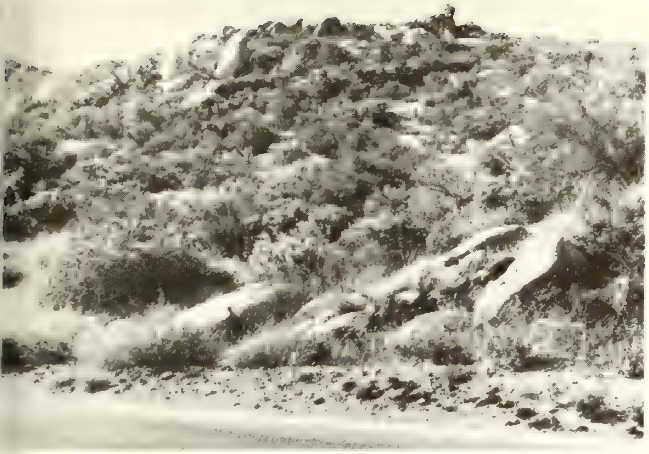


Figure 11—A Chamise/Manzanita/Sugarbush Association on Mt. San Jacinto near Banning, California. Chamise dominates the shrub layer, and manzanita and sugarbush are the characteristic associated species of this community; for classification purposes, this would be considered a one-layered Association.

The first species listed in an Association name will always the dominant species of the Association, and will be the minant overstory species. Therefore, a Jeffrey Pine/Sagesh Association will have Jeffrey pine as the dominant rstory species.

The order of species in the Association name reflects the er of dominance in the Association. The order of domiice can be taken in two ways: We can recognize the domit species in each layer of a multilayered stand, and write the cies names in descending order of dominance by layers; we recognize the dominant species in the dominant layer erstory) of an Association, and recognize characteristic ociated species within the same layer. The second approach nost appropriate for single-layered Associations, but may asionally be used for two-layered Associations when there good reason for doing so. Layer dominance should take cedence over within-layer species dominance when naming Association.

multilayered Association will be named by the dominant cies in each layer, beginning with the overstory layer, and ing with the herbaceous layer if one exists. Each species ne will be separated by a slash. Example: Jeffrey e/Sagebrush/Squirreltail grass.

n Association with mixed species dominance will be ned in the usual manner, with the exception that the place in Association name that is normally relegated to a single minant species will be occupied by more than one cies—separated by a hyphen. Example: A Jeffrey Pine-ite Fir/Manzanita Association.

single-layered Association will be named by the dominant cies in the layer and the dominant associated species. Many parral Associations will be named in this manner (*fig. 11*). mples: A Chamise-Scrub Oak Association or a nothus-Manzanita-Chamise Association; in both cases, species that are named form a part of the single shrub layer he Association.

hrubs with trees and herbaceous vegetation with shrubs or s represent a special situation that warrants some attention. lassification system must provide criteria for class disination that are to some extent arbitrary. Consequently, will find savannah-like Associations with insufficient tree canopy cover to be called elements of the Woodland Formation; yet there may be enough trees in the Association to be ecologically significant. In cases like these, the ''unrecognized'' tree or shrub cover should be included in the Association name—at the end and enclosed in parentheses. Example: A Foxtail Fescue-Mustard (Blue Oak) Association. A rule of thumb to follow in such cases is: Whenever an element of the Shrub Formation has a tree canopy cover of 10 to 25 percent, or an element of the Herbaceous Formation has a tree or shrub canopy cover of 10 to 25 percent, the tree or shrub will be included parenthetically in the Association name.

Common names may be used for local application of the System, but Latin names should be used in official documents, reports, and regional, national, or international correspondence. Naming procedures will remain the same; the Latin species names will simply replace the common species names. Example: A Foxtail Fescue-Mustard (Blue Oak) Association will be properly called a *Festuca megalura-Brassica* (*Quercus douglasii*) Association, and will belong to the *Festuca* Series (rather than the Fescue Series).

Given the appropriate perspective, any Association will fall into the category of Ephemeral or Transient Associations. We will treat it from the standpoint of resource management planning and decisionmaking. The most consistent candidates for this category will be certain elements of the Herbaceous Formation. Many stands of nonperennial herbs will appear only because of an especially heavy rainy season—and will disappear for a number of years; their reappearance will often be with a different species dominance, and a different species composition in general. Other stands may be composed of pioneer species that appear after a recent disturbance; the composition of these stands may change from year to year. These communities should not be treated with a greater degree of precision than is warranted by current management needs or by requirements for advancing the state of our knowledge. It may be sufficient to note the fact that there are elements of the Herbaceous Formation or perhaps classify them to Series. On the other hand, it may be desirable to assign them to at least a provisional Association without carrying out an extensive inventory. Judgment will have to be used in these kinds of cases.

Table 1—*Series distribution, by climate regions and habitats*

Subformation and Series	Climate regions[1]									Habitats[2]	
	Al	HMo	Mo	Co	Tr	IV	DTr	HDV	LDV	Rip	Alk
Closed Forest Formation											
Conifer Forest											
Cypress				×	×						
Bigcone Douglas-fir			×	×	×						
Douglas-fir			×	×							
Santa Lucia Fir				×							
White Fir		×	×								
Western Juniper		×	×								
Bishop Pine				×							
Bristlecone Pine	×	×									
Coulter Pine			×		×						
Knobcone Pine			×		×						
Limber Pine	×	×									
Lodgepole Pine		×	×								
Monterey Pine				×							
Ponderosa/Jeffrey Pine				×							
Torrey Pine				×							
Coast Redwood				×							
Mixed Conifer			×	×							
Broadleaf Forest											
Alder			×		×					×	
Aspen		×	×							×	
California Bay				×						×	
Eucalyptus						×					
Island Ironwood				×							
Madrone				×	×						
Bigleaf Maple			×	×	×					×	
Black Oak			×	×							
Canyon Live Oak			×	×			×				
Coast Live Oak			×	×	×	×					
Tanoak				×	×						
Woodland Formation											
Conifer Woodland											
Juniper							×				
Digger Pine					×	×					
Pinyon Pine			×				×				
Broadleaf Woodland											
California Buckeye					×	×					
Cottonwood					×	×		×	×	×	
Desert Ironwood									×	×	
Mesquite								×	×		
Blue Oak					×	×					
Engelmann Oak						×					
Interior Live Oak			×		×		×				
Valley Oak						×					
Palo Verde									×	×	
Salt-cedar								×	×	×	
Smoke Tree									×	×	
Sycamore					×	×				×	
Desert Willow									×	×	
Willow		×	×	×	×	×	×	×	×	×	
Succulent Woodland											
Joshua Tree			×				×	×			
Palm									×	×	
Shrub Formation											
Chaparral											
Ceanothus				×	×	×	×				
Chamise				×	×	×	×				
Bush Chinquapin		×									
Mountain Mahogany			×		×		×				
Manzanita		×	×		×		×				
Scrub Oak			×	×	×		×				
Prunus				×	×						
Redshank					×		×				
Sumac				×	×						
Toyon				×	×						
Soft Chaparral											
Baccharis				×		×		×	×	×	
California Buckwheat				×		×	×				
Coastal Sagebrush				×		×					
Croton									×		
Encelia						×			×		
Lupine				×							
Rabbitbrush			×				×	×			
Salvia				×	×	×					
Woody Shrub											
Arrowweed									×	×	
Blackbush							×	×			
Catclaw									×		
Creosote								×	×		
Greasewood								×			
Ocotillo									×		
Wild Rose			×	×	×	×				×	
Sagebrush			×				×				
Saltbush								×	×		
Succulent Shrub											
Agave							×		×		
Iodine Bush								×	×	×	
Opuntia				×				×	×		
Dwarf Shrub Formation											
Cushion Plant											
Buckwheat	×										
Succulent Dwarf Shrub											
Pickleweed				×				×	×	×	
Suaeda				×		×		×	×		
Herbaceous Formation											
Graminoid											
Bromegrass			×	×	×	×					
Bulrush		×	×	×	×	×	×	×	×	×	
Cattail (*Typha*)		×	×	×	×	×	×	×	×	×	
Cordgrass			×	×			×				
Fescue				×	×	×					
Galleta Grass							×	×	×		
Muhlenbergia			×		×		×			×	
Needlegrass				×		×					
Wild Oats				×	×	×					
Ricegrass			×				×	×			
Wild Rye			×								
Sacaton						×		×	×	×	
Saltgrass			×	×		×		×			
Sedge (*Carex*)	×	×	×	×	×	×	×	×	×	×	
Wiregrass (*Juncus*)	×	×	×	×	×	×	×	×	×	×	

e 1—*Series distribution, by climate regions and habitats*—continued

formation and es	Climate regions[1]									Habitats[2]	
	Al	HMo	Mo	Co	Tr	IV	DTr	HDV	LDV	Rip	Alk
baceous Formation											
orb											
Ambrosia				×							
Coldenia				×							
Goldenrod			×		×						
Mustard		×	×	×	×	×					
Wyethia					×	×					
quatic											
Pondweed		×	×	×	×	×	×	×	×		
Water Hyacinth		×	×	×	×	×	×	×	×		
Water Milfoil		×	×	×	×	×	×	×	×		
ryptogam											
Fern	×	×	×	×	×	×	×	×	×		
Lichen	×	×	×	×	×	×	×	×	×		
Moss	×	×	×	×	×	×	×	×	×		

= Alpine; HMo = High Montane; Mo = Montane; Co = Coastal; Tr = nsition; IV = Interior Valley; DTr = Desert Transition; HDV = High ert Valley; LDV = Low Desert Valley. For description, see Appendix A.

= Riparian; Alk = Alkaline soil.

FIELD KEY TO SUBFORMATIONS

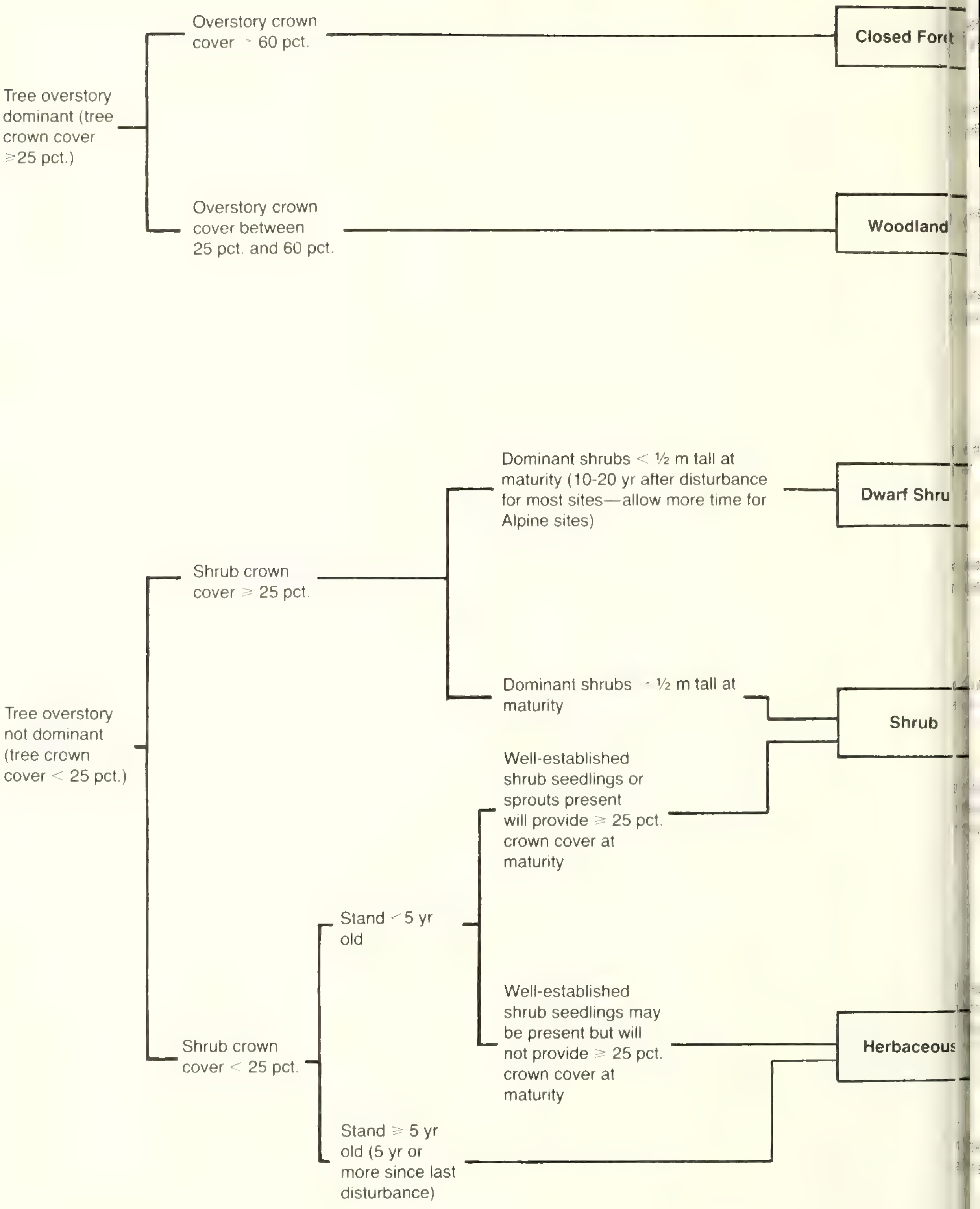
The following key may be used to identify Subformations in southern California. It is arranged in two parts: a key to Formations, and a key to Subformations. *Table 1* contains a list of Series keyed to the climate regions within which they most often occur. Series are identified by the dominant species present in a stand; therefore a dichotomous Series key is not necessary—a plant species key would be the necessary tool for determining Series. Associations will have to be identified at the site; for the present time, a key to Associations is not feasible.

Suggestions for Field Use of the Key. When using the key and *table 1* to interpret vegetation on the ground,

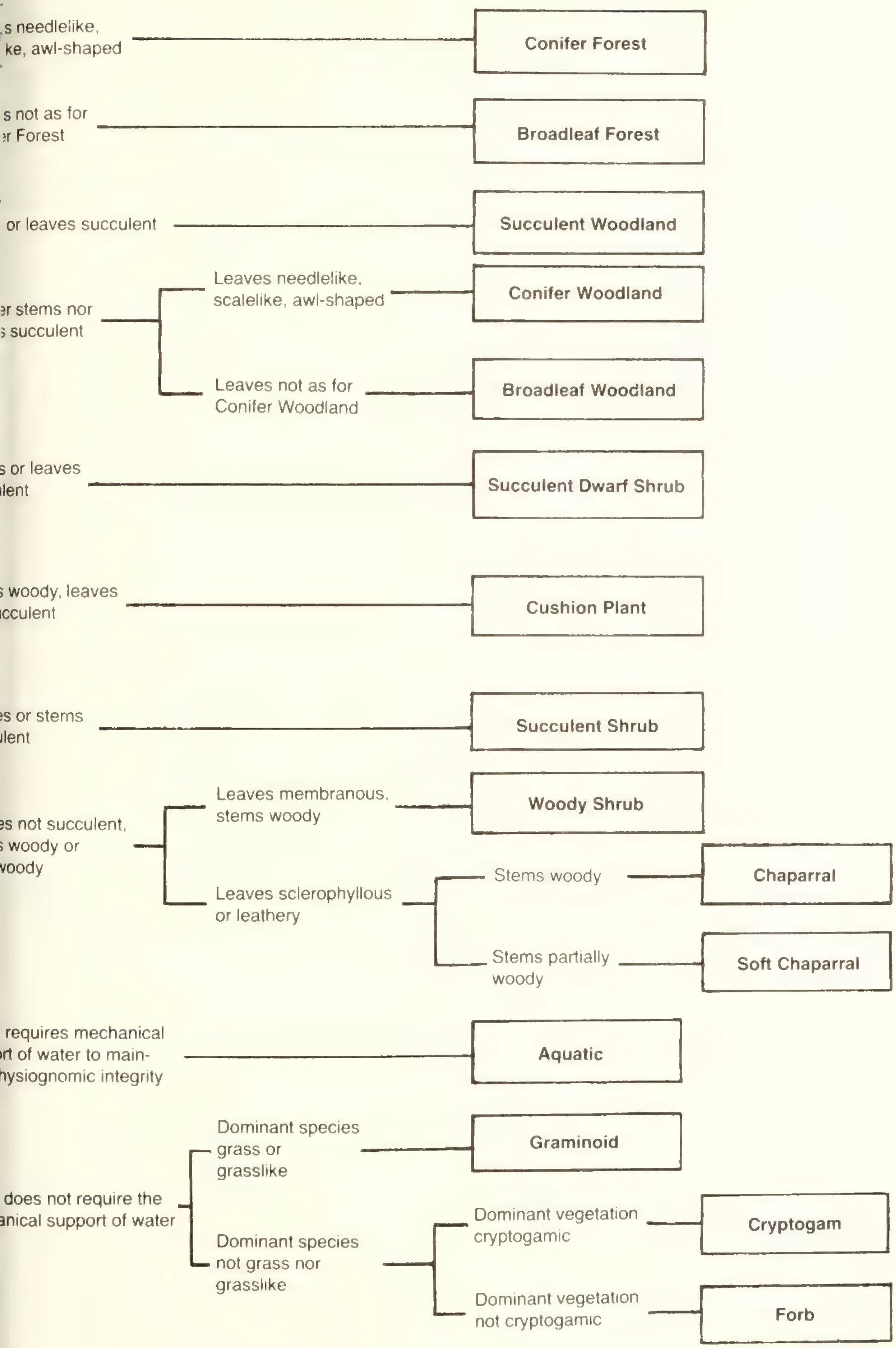
- Look at the variability across the landscape.
- Determine whether the variability can be explained by some ecological factor, i.e., soil differences, aspect differences, evaluation differences, changes in land form, etc. Specific communities may be related to unique combinations of these factors. For example: The Manzanita Series dominates northwest aspects, the Chamise Series dominates ridgetops and southeast aspects, and steep canyons contain the Bigcone Douglas-fir Series.
- If the overstory dominance is not clear, determine whether you are operating in an ecotone. Are understory or associated plants more characteristic of the Series present on either end of the ecotone? For example: As elevation increases, creosote bush drops out of the overstory and juniper, although present, does not replace it in dominance. Are the associated species more characteristic of the Creosote Series or the Juniper Series?
- Make the best interpretation possible based on your experience and ability to distinguish patterns in situations where interpretation is difficult (*fig. 12*). Distribution patterns for overstory species may be disrupted owing to local species competition, seed dispersal mechanisms and patterns, fire history, floristic history, or human use of the site. Most Associations that are identified in the field should be considered provisional until they can be placed within the context of general vegetation distribution patterns in a floristic region or zone.

Figure 12—Intepreting vegetation on the ground can be complicated by a variety of Associations. Elements of the Redshank, Chamise, Interior Live Oak, and Coulter Pine Series intermingle in the interface zone between brushland and timberland.

KEY TO FORMATIONS


Tree overstory dominant (tree crown cover ≥25 pct.)
Overstory crown cover > 60 pct.
Closed For
Overstory crown cover between 25 pct. and 60 pct.
Woodland
Tree overstory not dominant (tree crown cover < 25 pct.)
Shrub crown cover ≥ 25 pct.
Dominant shrubs < ½ m tall at maturity (10-20 yr after disturbance for most sites—allow more time for Alpine sites)
Dwarf Shru
Dominant shrubs > ½ m tall at maturity
Shrub
Shrub crown cover < 25 pct.
Stand < 5 yr old
Well-established shrub seedlings or sprouts present will provide ≥ 25 pct. crown cover at maturity
Well-established shrub seedlings may be present but will not provide ≥ 25 pct. crown cover at maturity
Herbaceou
Stand ≥ 5 yr old (5 yr or more since last disturbance)

KEY TO SUBFORMATIONS



SERIES DESCRIPTIONS

Closed Forest Formation

Vegetation: The Series and Subformations of the Closed Forest Formation are dominated by deciduous or evergreen trees that are at least 15 feet (5 m) tall, with crowns mostly interlocking (UNESCO 1973). Since many "forested" areas are only marginally capable of supporting a true closed forest, stands with an overstory crown cover of at least 60 percent will qualify as closed forests. The Closed Forest Formation is comprised of the Conifer and Broadleaf Subformations. The Conifer Subformation contains Series that are dominated by conifer species, and the Broadleaf Subformation contains Series that are dominated by evergreen or deciduous broadleaf species—broadleaf forests are sometimes described as hardwood or mixed-evergreen forests.

Distribution: The Closed Forest Formation is worldwide in distribution. Elements of the Conifer Forest Subformation occur from sea level near the coast to above 11,000 feet (3353 m) in the interior of southern California. The Broadleaf Forest Subformation is found in the coastal and interior mountain ranges of southern California, and also in some riparian habitats.

Suggested Phases are:

Size (d.b.h., 2 inches)	*Cover (percent)*	
	Overstory	*Understory*
1. <1	1. <25	1. <10
2. 1-5	2. 10-25	2. 10-25
3. 5-11	3. >60	3. 25-50
4. 11-21		4. 50-70
5. >21, <180 yrs		5. >70
6. >21, >180 yrs		

Conifer Forest Subformation

Series within the Conifer Forest Subformation are named for the dominant overstory species, usually that species which makes up 60 percent or more *of the total crown cover.* In a Mixed Conifer Series, two or three specified codominants make up 60 percent or more of the total crown cover (*fig. 13*).

Cypress Series

Vegetation: Dominant overstory may be Sargent cypress (*Cupressus sargentii*), Monterey cypress (*C. macrocarpa*), Gowan cypress (*C. goveniana*), Tecate cypress (*C. forbesii*), Cuyamaca cypress (*C. stephensii*), or Santa Cruz cypress (*C. abramsiana*). Disjunct stands of cypress, usually with only one dominant species per stand, occur within the Chaparral and Conifer Forest Formations. Chaparral shrubs often occur in the understory. Cypress stands occur on serpentine or low-nutrient soils.

Distribution: Localized populations of cypress are present in the Santa Cruz Mountains (*C. abramsiana*), Santa Ana Mountains, Otay Mountains, Baja California (*C. forbesii*), and Monterey Peninsula (*C. goveniana, C. macrocarpa*), from Mendocino County to Santa Barbara County (*C. sargentii*), and on Cuyamaca Peak in San Diego County (*C. stephensii*).

Bigcone Douglas-fir Series

Vegetation: Overstory species is *Pseudotsuga macrocarpa* with *Quercus chrysolepis* (canyon live oak) and occasional black oak (*Q. kelloggii*). Dense stands are found in canyons or on north-facing slopes (*fig. 14*). Mature stands have a sparse herbaceous layer. Younger stands may have a chaparral shrub understory.

Distribution: The total range of bigcone Douglas-fir is within southern California, from near Mount Pinos in Kern County south to San Diego County.

Douglas-fir Series

Vegetation: Pseudotsuga menziesii is the dominant overstory species. Representatives of this Series may occur as extensive "pure" stands or be intermingled with elements of the Coast Redwood or Monterey Pine Series.

Distribution: The most extensive stands of Douglas-fir are in western Oregon and Washington, though the species grows throughout the Western States ranging from British Columbia south to Mexico. Within California, the species dominates stands through the Klamath and Coast Ranges to the Santa Cruz Mountains. Isolated stands occur in Monterey County.

Santa Lucia Fir Series

Vegetation: Abies bracteata is the dominant species. Stands are interspersed with the Broadleaf Forest Formation in steep, rocky, fire-resistant habitats.

Distribution: This Series has a restricted distribution consisting of relict stands within 15 miles (24.14 km) of the coast in the Santa Lucia Mountains of Monterey and San Luis Obispo Counties.

White Fir Series

Vegetation: Abies concolor is the dominant overstory species, and may occur in nearly pure stands. The understory vegetation is sparse with a moderate accumulation of litter including needles and fallen branches.

Distribution: White fir is widely distributed in the Western States from Oregon to New Mexico and south into Mexico. Small relict stands in the mountains of the north Mojave Desert appear more closely related genetically to the white fir of the Rocky Mountains than to the white fir of California.

Western Juniper Series

Vegetation: Juniperus occidentalis is the dominant overstory species, found in sparse stands with sparse shrubby understory of *Artemisia* (sagebrush) and *Chrysothamnus* (rabbitbrush) species.

Distribution: Western juniper extends from southern Washington throughout the Great Basin area of the West with disjunct populations in the mountains of southern California.

Bishop Pine Series

Vegetation: Pinus muricata is the dominant species with chaparral shrubs in the understory. Growth habit can be twisted, when the tree is subjected to winds and salt spray, or straight with a broad crown where it is protected from the wind.

Distribution: Intermittent relict stands range from Humboldt County south to Santa Barbara County and the Channel nds. Bishop pine grows within the fog belt along the Pacific st.

ristlecone Pine Series

egetation: Pinus aristata (named *P. longaeva* by Bailey 70]) is the dominant overstory species occurring in sparse ds with limber pines. This Series is found on dolomitic s at the upper elevational limits of the conifer forest. It is rspersed with the Dwarf Shrub Formation in alpine itats.

istribution: Bristlecone pine extends west from Utah into County in California where it is found in the White, Last nce, Inyo, and Panamint Mountains.

oulter Pine Series

egetation: Pinus coulteri is the dominant overstory species 1 chaparral shrubs or interior live oaks in the understory *15*). This Series interfaces with the Chaparral Formation.

istribution: Coulter pine ranges from Contra Costa County th to Baja California.

nobcone Pine Series

egetation: Pinus attenuata is the dominant overstory spe- with chaparral shrubs in the understory. This Series inter- s with the Chaparral Formation throughout much of its ge and also occurs on serpentine soils with the Conifer est Formation.

istribution: Knobcone pine occurs from the Oregon Cas- es south to Baja California.

imber Pine Series

egetation: Pinus flexilis is the dominant overstory species, balpine tree growing in sparse stands with a sparse under- y. Above 11,000 feet (3352.8 m) elevation, limber pine ds to form krummholtz stands, the prostrate forms appear- more like shrubs than ancient trees.

istribution: Limber pine ranges from Canada to New xico in the mountains of the Western United States. South- California stands are scattered on the highest peaks of the , Panamint, San Gabriel, San Bernardino, and San Jacinto untain ranges. The western limit is on Mount Pinos in Kern nty.

odgepole Pine Series

egetation: Pinus contorta is the dominant overstory spe- , in sparse stands within xeric, high-elevation habitats or in se stands surrounding meadows. Understory also varies ording to habitat.

istribution: Lodgepole pine ranges from Alaska to Baja ifornia and east to South Dakota. It grows in a wider range levations—sea level to 12,000 feet (3657.6 m)—than any r pine (Griffin and Critchfield 1972). In southern Califor- this Series is a dominant one above 8000 feet (2438.4 m). vever, Bluff Lake Meadow, at 7200 feet (2194.6 m), in the Bernardino Mountains, supports a small stand of gepole pine including the Champion Lodgepole.[7]

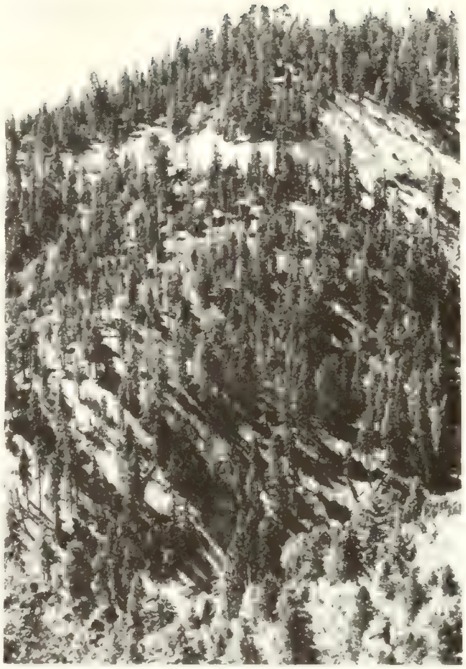


Figure 13—A classic example of the Mixed Conifer Series on steep, rugged terrain. An admixture of black oak can be seen with the dominant sugar pine and white fir. Because of the steep topography, litter accumulation is low.

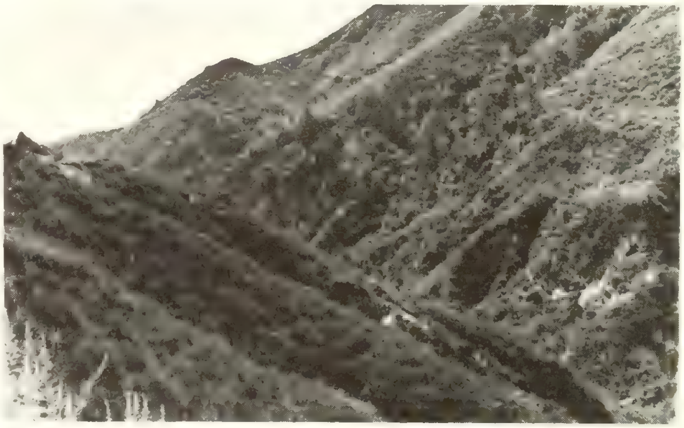


Figure 14—Repeated fires have often relegated the Bigcone Douglas-fir Series to protected drainage bottoms in many parts of southern California.

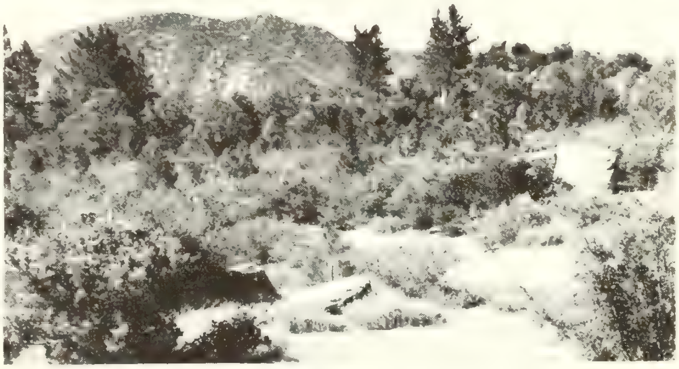


Figure 15—An early Phase Coulter Pine/Interior Live Oak Association 5 years after a fire. The emergent Coulter pine has attained sufficient dominance to qualify this stand as an element of the Closed Forest Formation. Ceanothus and manzanita can also be seen in the shrub layer.

American Forestry Association. June 3, 1963. Report to the Forest Super- r, San Bernardino National Forest, San Bernardino, Calif.

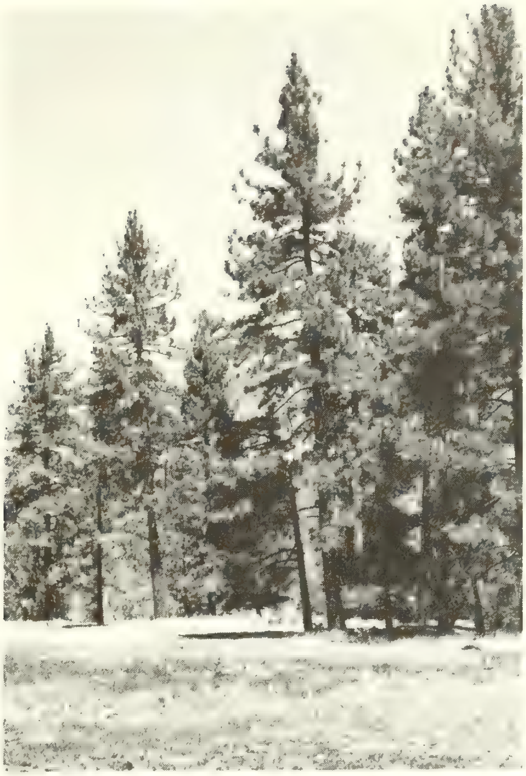


Figure 16—A mature Jeffrey Pine/Interior Live Oak/Bromegrass Association represents the Closed Forest Formation in the middle ground, and the Herbaceous Formation can be seen in the foreground. Environmental factors have maintained the distinction between the herbaceous layer of the Closed Forest Formation and the Herbaceous Formation.

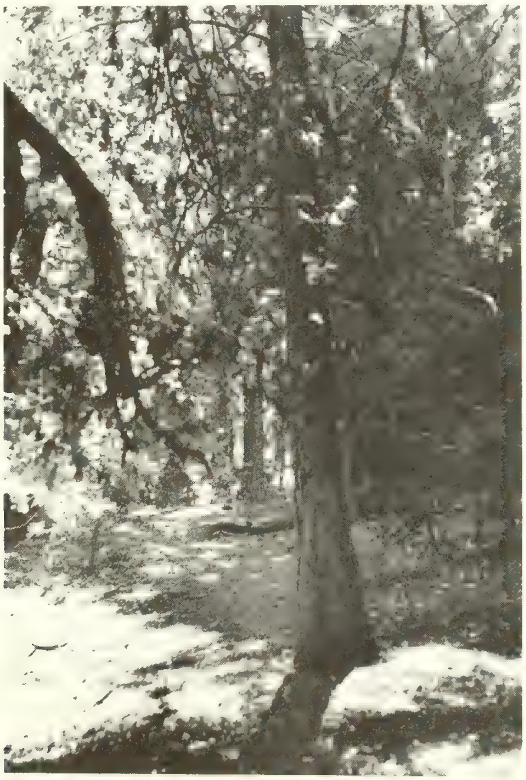


Figure 17—The interior of a stand belonging to the Mixed Conifer Series. In spite of the heavy use given to this stand (foot traffic), Jeffrey pine, white fir, and black oak seedlings are well established in the understory.

Monterey Pine Series

Vegetation: Pinus radiata is the dominant overstory specie in open to moderately dense stands with live oaks and cypres Shrubs and perennial herbs occupy the understory.

Distribution: Relict stands are present within the coastal fo belt at three different locations in central California: An Nuevo, Monterey Peninsula, and Cambria Hills.

Ponderosa/Jeffrey Pine Series

Vegetation: Dominant overstory species are *Pinus ponderosa* or *P. jeffreyi* with herbaceous or shrubby understor (*fig. 16*).

Distribution: Ponderosa pine is present in dominant stand in mountains throughout the Western States. Jeffrey pin ranges from southern Oregon to mountains of Baja California Jeffrey pine generally occurs on the drier or higher elevatio sites and ponderosa pine occupies the most mesic midelevatio habitats where the ranges of the two species coincide.

Torrey Pine Series

Vegetation: Relict stands of *Pinus torreyana* form a spars overstory with soft chaparral shrubs in the understory.

Distribution: Sea bluffs at Del Mar in San Diego County and on Santa Rosa Island are the only remaining habitats fo relict stands of Torrey pine.

Coast Redwood Series

Vegetation: Sequoia sempervirens is dominant in mixe stands with California laurel (*Umbellularia californica*) an Douglas-fir (*Pseudotsuga menziesii*). Mosses and ferns ofte grow in the understory. A deep litter layer covers the soil.

Distribution: Coast redwood occurs in discontinuous stand from southern Oregon south to San Luis Obispo County i California, growing within 30 miles (48.3 km) of the Pacifi Coast.

Mixed Conifer Series

Vegetation: Overstory components are a mix of *Pinus lambertiana* (sugar pine), *Abies concolor* (white fir), *Pinus ponderosa* (ponderosa pine), or *Pinus jeffreyi* (Jeffrey pine), an *Calocedrus decurrens* (incense-cedar). The overstory is multistoried in dense stands with moderate to heavy litter accumulations (*fig. 17*).

Distribution: Mixed Conifer occurs throughout the California mountains, north into Oregon, and south into the Sierr San Pedro Martir of Baja California.

Broadleaf Forest Subformation

Series within the Broadleaf Forest Subformation are name for the dominant overstory species. Four represent strictly riparian habitats in southern California although they may occur outside of riparian areas in more mesic environments. One (*Eucalyptus*) represents introduced species which have become naturalized.

Alder Series

Vegetation: Alnus rhombifolia or *A. rubra* is the dominant overstory species in this Series, which occurs in riparian habitats with flowing water. Understory shrubs, such as *Ribes* and *Salix* species, with abundant herbaceous vegetation, make this a multistoried, diverse habitat.

Distribution: Alnus rhombifolia (white alder) is found throughout California, except for the Pacific Coast, where it is placed by *A. rubra* (red alder). White alder ranges north into itish Columbia and east to Idaho.

Aspen Series

Vegetation: Populus tremuloides is the dominant overstory ecies. The Series occurs around moist mountain meadows.

Distribution: Aspen ranges from Alaska through Canada d the United States to Mexico. Southern California populans are disjunct, occurring in the White Mountains and San rnardino Mountains.

California Bay Series

Vegetation: Dominant overstory is *Umbellularia califora* with shrubs in the understory.

Distribution: California bay extends from San Diego unty north to southwest Oregon. It is present along streamurses or springs in southern California and on coastal footls north of Ventura County and on the Channel Islands.

Eucalyptus Series

Vegetation: Eucalyptus occurs in dominant stands with a nse litter layer and essentially no shrubs or herbaceous ecies in the understory.

Distribution: Native to Australia, this genus has been anted in dense stands widely scattered through California d has become naturalized, with some reproduction occurg. No exact distribution inventory exists.

Island Ironwood Series

Vegetation: Dominant overstory is *Lyonothamnus floribuns* with a shrubby understory.

Distribution: Island ironwood occurs in Santa Catalina Isnd and a subspecies (*asplenifolius*) with pinnate leaves is und on San Clemente, Santa Rosa, and Santa Cruz Islands.

Madrone Series

Vegetation: Arbutus menziesii is the dominant overstory ecies. The Series is often intermingled with both Coast dwood and Douglas-fir Series.

Distribution: Madrone occurs in a few relict stands in south- California—on Palomar Mountain, the Santa Monica ountains, and Santa Cruz Islands. From the Santa Lucia ountains northward to British Columbia madrone is comon, both as a Series dominant and as a component of the ast Redwood Series and Douglas-fir Series.

Bigleaf Maple Series

Vegetation: Acer macrophyllum, a deciduous tree, is the minant overstory species. The Series is riparian in southern lifornia, but spreads over hillsides away from streams in the rth.

Distribution: Bigleaf maple is found along the coast from itish Columbia to San Diego County in southern California. e Series occurs on the west slopes of the Sierra Nevada ountains and in the Peninsular and Transverse Ranges, but es not follow rivers into the Central Valley.

Black Oak Series

Vegetation: Quercus kelloggii is the dominant overstory ecies—a deciduous tree which produces a well-developed ter layer. Understory includes shrubs, grasses, and perennial rbs. Black oak will sometimes survive fire and resprout from e crown. If crowns are fire killed, it resprouts from the base.

Distribution: Black oak occurs from Oregon south to the guna Mountains in San Diego County (*fig. 18*).

Figure 18—The Black Oak Series is a common Broadleaf Forest element in southern California.

Canyon Live Oak Series

Vegetation: Quercus chrysolepis is the dominant overstory tree. This Series can occur in riparian habitats, interfacing the Chaparral Formation, or on mountain sideslopes at higher elevations. This species is usually fire-killed, resprouting from the base rather than the crown.

Distribution: Canyon live oak occurs from southwestern Oregon to Baja California, east to central Arizona.

Coast Live Oak Series

Vegetation: Quercus agrifolia is the dominant overstory species (*fig. 19*). Under optimum growth the Series is a dense forest, but it sometimes forms open savannah-like grasslands. This live oak has exceptional fire resistance. Trees greater than 8 inches (20.3 cm) d.b.h. will resist top kill, resprouting from the crown within 2 months after being totally blackened.[8]

Distribution: Coast live oak occurs from Mendocino County south to Baja California.

Tanoak Series

Vegetation: Lithocarpus densiflorus is the dominant overstory species often associated with madrone (*Arbutus menziesii*). Tanoak grows in a shrubby form on rocky, exposed ridges.

Distribution: Tanoak occurs from southwestern Oregon south to Santa Barbara County in California. It is the only North American representative of a large Asian genus.

Woodland Formation

Vegetation: Dominant trees are more than 15 feet (5 m) tall, with an open canopy. Crowns are not touching and canopy cover is between 25 and 60 percent. Both herbaceous and shrubby understories can be present. Trees may be deciduous or evergreen, and may be conifers or broadleaf species. Three Subformations are included in the Woodland Formation: The

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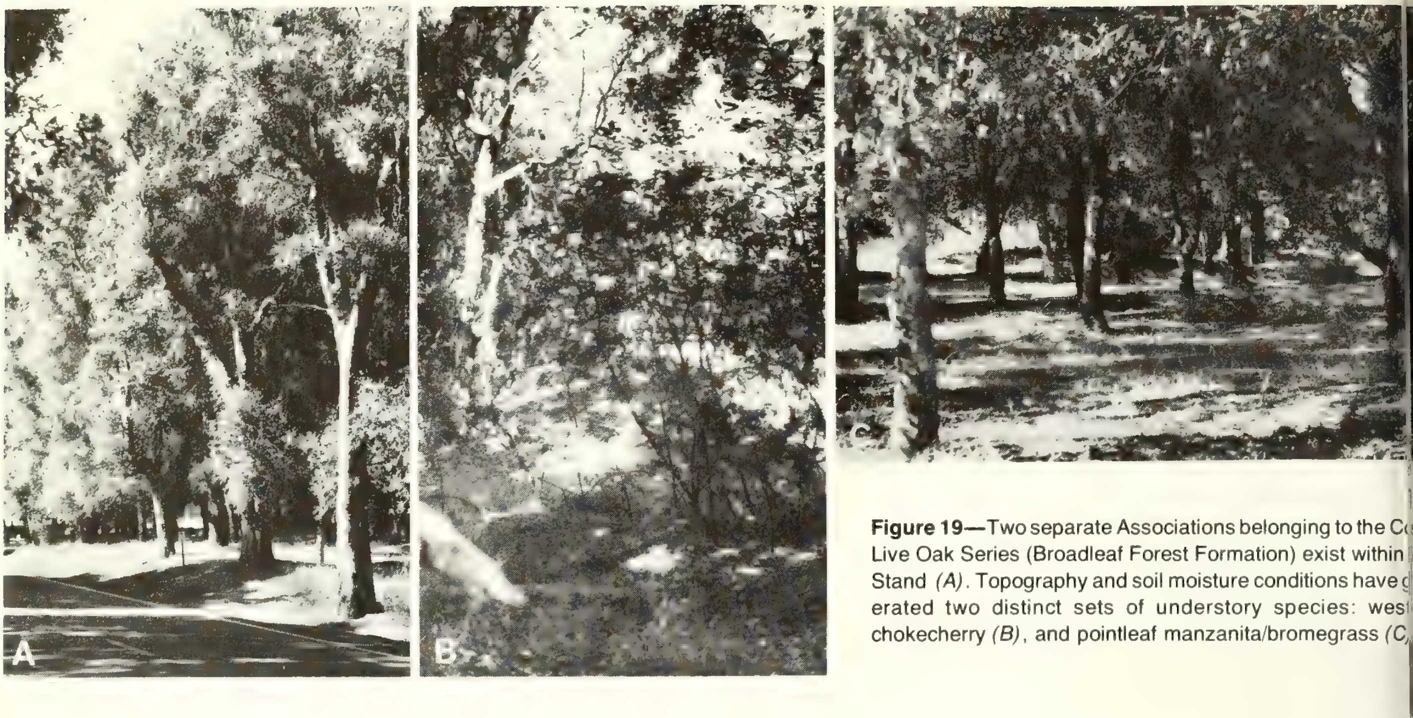
[8] Plumb, T.R. 1976. Response of Southern California oaks to wildfire. (Report on file at the Forest Fire Laboratory, Pacific Southwest Forest and Range Experiment Station, Riverside, Calif.)

Clemson University Library


A

B

C

Figure 19—Two separate Associations belonging to the Coast Live Oak Series (Broadleaf Forest Formation) exist within this Stand *(A)*. Topography and soil moisture conditions have generated two distinct sets of understory species: western chokecherry *(B)*, and pointleaf manzanita/bromegrass *(C)*.

Conifer Woodland, Broadleaf Woodland, and Succulent Woodland Subformations.

Distribution: Woodlands occur worldwide. In southern California, they occupy riparian habitats, valley savannahs, and foothill and mountain habitats. Seven Series in the Woodland Subformation occupy desert riparian habitats exclusively, including dry washes and oases. Most of the remaining Series occupy riparian as well as nonriparian habitats, varying in density and understory as the habitat changes from xeric to mesic.

Suggested Phases are:

Size (d.b.h., 2 inches)	*Cover (percent)*	
	Overstory	*Understory*
1. <1	1. <25	1. <10
2. 1-5	2. 10-25	2. 10-25
3. 5-11	3. 25-60	3. 25-50
4. 11-21		4. 50-70
5. >21		5. >70

Conifer Woodland Subformation *(fig. 20)*

Juniper Series

Vegetation: Dominant overstory vegetation species is either *Juniperus californica* or *J. osteosperma,* with desert and chaparral shrubs in the understory. *J. californica* is an arborescent shrub.

Distribution: Utah juniper, *Juniperus osteosperma,* ranges into California from the Great Basin and is present in spotty distributions from Inyo County to eastern Los Angeles County in the San Gabriel Mountains. California juniper, *J. californica,* occurs from Tehama County south to San Diego County.

Digger Pine Series

Vegetation: Pinus sabiniana is the dominant overstory species. Digger pine sometimes occurs as inclusions within the Broadleaf Forest Formation. Understory vegetation is mainly grass and forbs.

Distribution: The total distribution of this species is within California, in foothills from Shasta County south to Los Angeles County.

Pinyon Pine Series *(fig. 21)*

Vegetation: Pinus monophylla or *P. quadrifolia* are dominant overstory species, with shrubs in the understory.

Distribution: In southern California, pinyon pine occurs in desert mountains from Inyo County west to Santa Barbara County and south to San Diego County. *Pinus monophylla* ranges from Idaho to Baja California. *P. quadrifolia* extends into southern California from Baja California as far north as Riverside County.

Broadleaf Woodland Subformation

California Buckeye Series

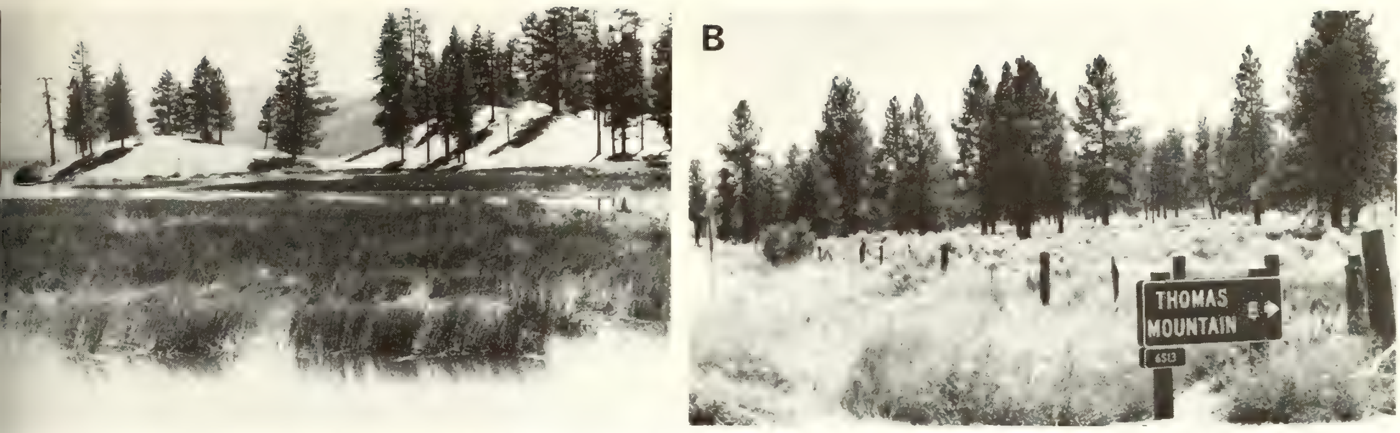
Vegetation: Aesculus californica is the dominant overstory species, forming dense stands on hillsides or extending into valleys along rivers or streams. California buckeye is a deciduous tree with a shrubby form.

Distribution: The total distribution of this species is within California. It surrounds the Central Valley from Shasta County south to Los Angeles County.

Cottonwood Series

Vegetation: Dominant overstory species are *Populus fremontii* or *P. trichocarpa.* Both are riparian species and are deciduous. Fremont cottonwood, *Populus fremontii,* follows streams and dry washes at low elevations. Black cottonwood, *P. trichocarpa,* occurs at higher elevations in southern California.

Distribution: Both species of cottonwood are present throughout California. Black cottonwood ranges from Baja California throughout the West and north to Alaska. Fremont cottonwood covers the Southwest to Texas and Mexico.



ure 20—The Jeffrey pine stand near Big Bear Lake *(A)* and the Jeffrey Pine/Sagebrush Association in *B* both raise the question as to whether a Jeffrey e Series should be included in the Conifer Woodland Subformation. These stands may simply represent extreme, but acceptable, density variation within Closed Forest Formation.

ure 21—The Pinyon Pine/Sagebrush Association is an element of the ifer Woodland Formation. A distinct environmental break defines the of the pinyon overstory and is an easily defined boundary for the ebrush Association (Shrub Formation) in the foreground.

)esert Ironwood Series

'egetation: Olneya tesota is the dominant overstory spe-. This is a drought-deciduous California Sonoran Desert rian Series with a sparse understory. The wood is ex-nely hard and dense, and weathers very slowly in the desert nate. Ironwood has an ability to go dormant and survive ught longer than riparian species. Seeds require scarifica-by tumbling in flash floods for germination.

)istribution: Desert ironwood ranges from the California oran Desert to Arizona and south to Mexico.

Mesquite Series

'egetation: The dominant overstory is either honey mes-te, *Prosopis glandulosa* var. *torreyana*, or screwbean mes-te, *P. pubescens*. These are a drought-deciduous desert rian species occupying dry washes, oases, or moist seeps. derstory includes desert wash shrubs such as desert laven-, *Hyptis emoryi*, or desert broom, *Baccharis spp*.

)istribution: Honey mesquite is more prevalent in the Cali-ia Sonoran Desert and screwbean mesquite is the more mon Mojave Desert species. Both range from the San quin Valley south and east to Texas and Mexico.

3lue Oak Series

'egetation: Quercus douglasii is the dominant overstory cies with shrub or grass-forb understory. Blue oak is a deciduous tree growing in open savannah-like stands on valley floors and forming woodlands in the foothills.

Distribution: Blue oak surrounds the Central Valley, reaching northward into Shasta County, and south to Los Angeles County, and Santa Cruz and Santa Catalina Islands.

Engelmann Oak Series

Vegetation: Quercus engelmannii is the dominant overstory species, with soft chaparral shrubs, grasses, and forbs in the understory.

Distribution: Englemann oak has a scattered distribution from Los Angeles County south to Baja California, but the major extent of the Series distribution is in western San Diego County.

Interior Live Oak Series

Vegetation: Quercus wislizenii is the dominant overstory species with chaparral shrubs in the understory. This Series occupies xeric habitats between Chaparral and Forest Formations, but follows intermittent streams into Chaparral. The species is very sensitive to fire.[8] The larger trees are usually located in areas that have not burned in 50 to 100 years. More often this live oak is present in dense shrublike thickets with multiple stems, the result of resprouting from the base following fire.

Distribution: Interior live oak is generally a California species ranging from Siskiyou County south to Baja California.

Valley Oak Series

Vegetation: Quercus lobata is the dominant overstory species with shrub or grass/forb understory.

Distribution: Valley oak follows the same distribution as blue oak, from Shasta County south to Los Angeles County and the Channel Islands.

Palo Verde Series

Vegetation: The dominant overstory tree is palo verde, *Cercidium floridum* or *C. microphyllum*, with a sparse understory. These are drought-deciduous riparian trees. The Series is common in California Sonoran Desert dry washes or rocky bajadas. Tumbling in flash floods or abrasion by some other means is necessary for seed germination.

Distribution: Palo verde ranges through both California deserts to Arizona and Mexico.

Salt-cedar Series

Vegetation: Tamarix spp. are the dominant overstory trees. All are introduced from Asia or the Mediterranean region. They form dense thickets competing aggressively with native species. *Tamarix* has a high rate of transpiration and is sometimes blamed for lowering water tables. This Series occupies moist seeps and streambanks in the desert. *Tamarix* is often planted as a windbreak.

Distribution: Tamarix has become naturalized throughout the Southwest.

Smoke Tree Series

Vegetation: Dalea spinosa is the dominant overstory tree. This is a drought-deciduous desert riparian tree common to dry washes in the California Sonoran Desert. Seeds germinate after scarification, usually from tumbling in flash floods. The extent of past flooding can be inferred from the distribution of smoke trees (*fig. 22*).

Distribution: Smoke tree ranges from the southern Mojave Desert through the California Sonoran Desert to Arizona and Mexico.

Sycamore Series

Vegetation: The dominant overstory species is *Platanus racemosa*. Sycamores follow perennial and intermittent streams with a soft chaparral shrub and herbaceous understory.

Distribution: California sycamore ranges from Baja California north to Shasta County.

Desert Willow Series

Vegetation: Chilopsis linearis is the dominant overstory species. This is a drought-deciduous riparian species of the California Sonoran Desert and inland valleys of southern California. It is not related to willow, *Salix* spp., but has drooping elongated leaves similar to some willow species. Understory vegetation is sparse to moderate, consisting of soft chaparral and desert shrub species.

Distribution: Desert willow ranges from the Mojave and California Sonora Deserts south to Mexico and east to Texas.

Willow Series

Vegetation: Salix lasiolepis (arroyo willow), *S. gooddingii* (black willow), *S. hindsiana* (sandbar willow), and other *Salix* spp. are dominant overstory species. They may be trees or shrublike, and always indicate riparian habitats. The understory is herbaceous. Since willows are deciduous, dense stands have deep litter layers.

Distribution: The genus has worldwide distribution at all elevations. In southern California, the Series may occur wherever surface water or subsurface seeps are present.

Succulent Woodland Subformation

Joshua Tree Series *(fig. 23)*

Vegetation: The dominant overstory species is *Yucca brevifolia*. Understory shrubs include desert and chaparral species. The herbaceous understory varies from moderately dense in mountain foothills to virtually absent on the Mojave Desert. Joshua trees occur more often as a component of the Pinyon Series, or of shrub Series that occur in desert climates, than as a dominant overstory.

Distribution: The Joshua tree occurs in foothills and desert highlands surrounding the Mojave Desert, from San Bernardino County north to Inyo County, into Nevada and northe Arizona.

Palm Series

Vegetation: The dominant overstory is usually the Califo nia fan palm (*Washingtonia filifera*) with an understory shrubs and grasses. Occasionally date palms (*Phoenix* spp have become naturalized, and occur as dominants in the ove story. Cottonwoods and mesquites are sometimes present.

Distribution: The Palm Series is found in the Californi Sonora Desert and oases, which often follow earthquake-fau lines.

Shrub Formation

Vegetation: Elements of the Shrub Formation are dominate by shrubs that are between 1½ feet (½ m) and 15 feet (3 m) tal *at maturity*. Our definition of "shrub" includes succulent stemmed species (such as cactus) that are not normally calle shrubs. Evergreen sclerophyllous shrubs dominate Series i the Chaparral Subformation; the shrubs are adapted to fir resprouting or germinating following fire. The Soft Chaparra Subformation is dominated by shrubs with relatively littl woody tissue; woody tissue that is present is generally con fined to the basal portions of the shrubs. In terms of stan physiognomy and shrub morphology, we can, for practica purposes, describe the Woody Shrub Subformation as membranous-leaved analogue of the Chaparral Subformation some dominant species found in the Woody Shrub Subformation have survival mechanisms that allow them to maintair their existence in a fire regime, but adaptation to fire is not diagnostic character of this Subformation. The Woody Shrub Subformation includes some plant communities that occur ir dry desert habitats, and others that occur in mesic environments with a readily available supply of moisture Dominant species in the Succulent Shrub Subformation are succulent stemmed (e.g., *Opuntia* spp.) or have succulent leaves (*Allenrolfea* spp. and *Agave* spp.).

Distribution: The Shrub Formation is worldwide in distribution, and occurs in a wide range of habitats.

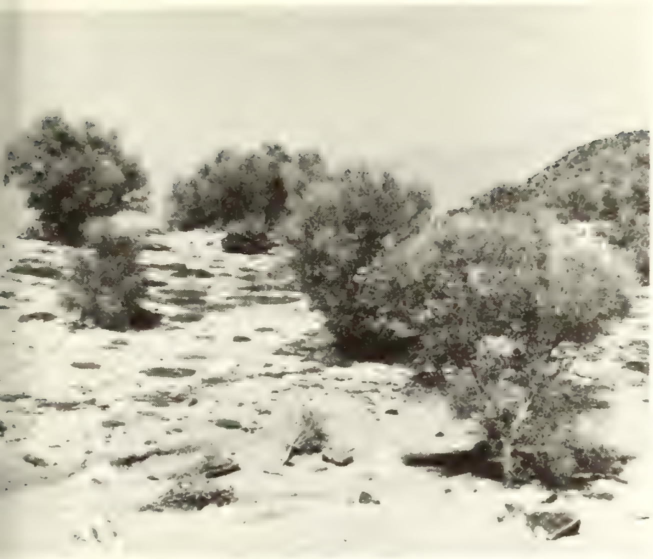
Suggested Phases are:

Cover (percent)			
Overstory	*Understory*	*Annual*	*Litter*
1. <5	1. <5	1. <2	Expressed
2. 5-10	2. 5-10	2. 2-10	in percent
3. 10-25	3. 10-25	3. 11-25	cover and
4. 25-50	4. 25-50	4. 25-50	composition
5. 50-70	5. 50-70	5. 50-70	
6. >70	6. >70	6. >70	

Chaparral Subformation *(fig. 24)*

Vegetation: Chaparral is dominated by evergreen sclerophyllous shrubs, mostly less than 15 feet tall (3 m). Shrubs are adapted to fire, resprouting or germinating following fire. Shrub crown cover at maturity is often close to 100 percent, although it can remain sparse on very steep or poor sites.

Distribution: Chaparral occurs throughout California, but is best developed in southern California. The Subformation extends from southern Oregon to central Arizona and Baja California.



ure 22—The Smoke Tree Series is a common representative of the adleaf Woodland Subformation in dry desert washes.

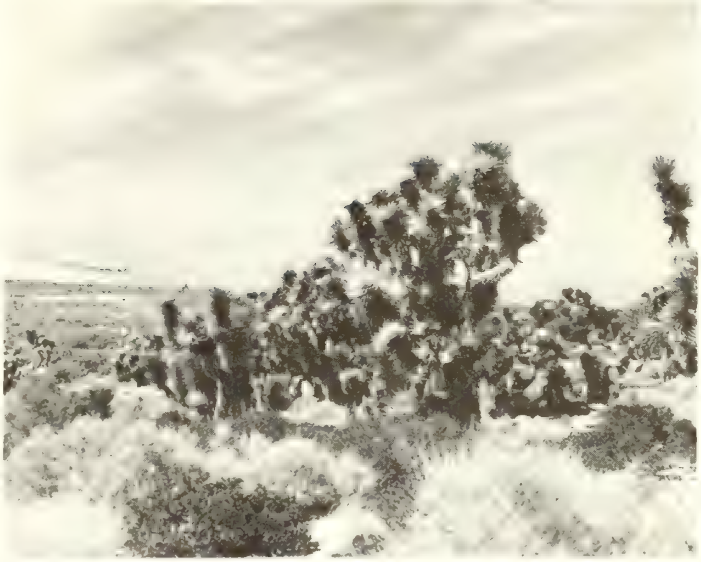
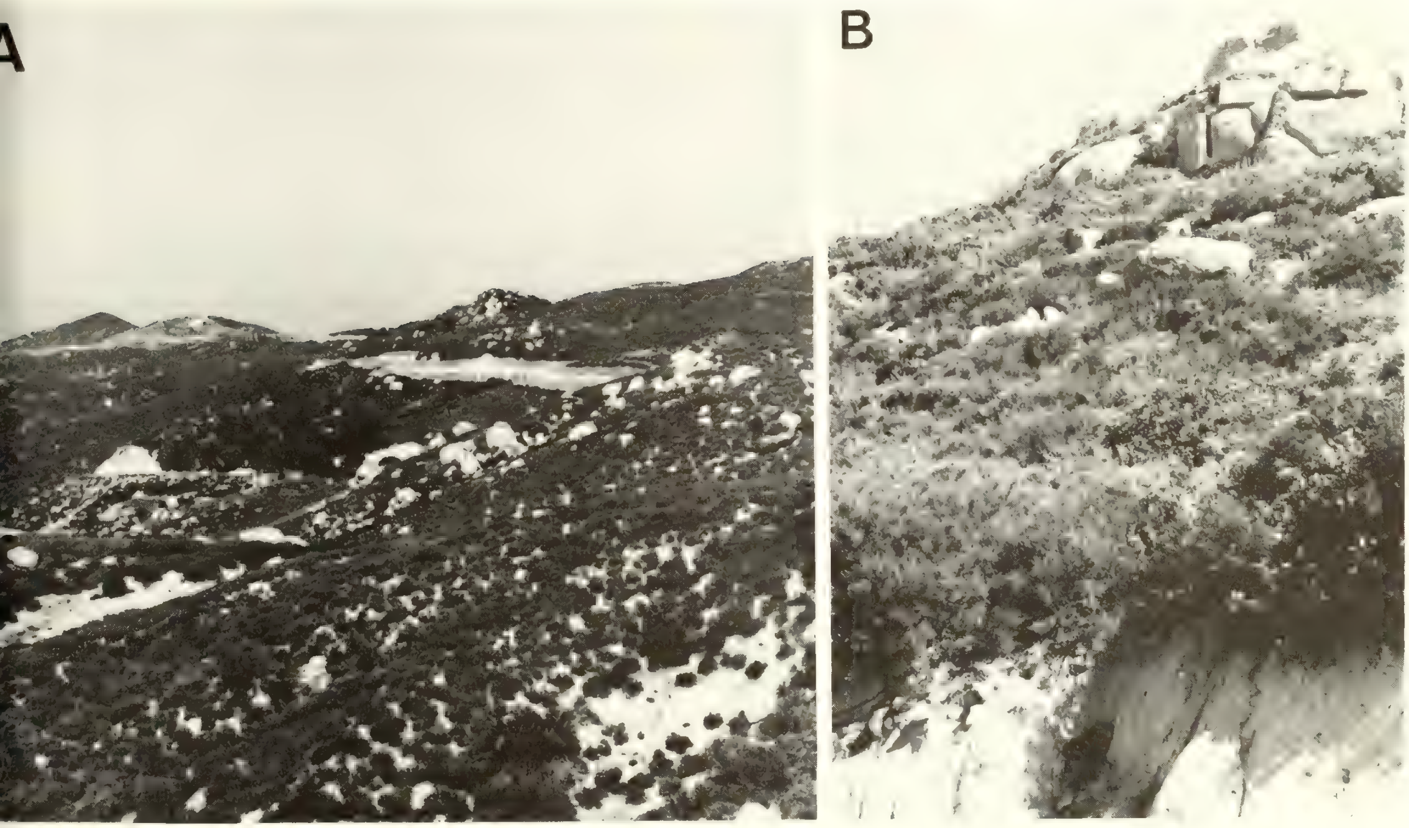


Figure 23—One of the two Series currently in the Succulent Woodland Subformation is represented by the Joshua Tree/Nevada Ephedra Association. Other associated species in this stand are cottonthorn (Tetradymia spinosa) and box-thorn (Lycium andersonii). Hairy Yerbasanta (Eriodictyon trichocalyx) occurs in disturbed areas.



ure 24—A complex of Associations dominated by elements of the Chamise, Manzanita, and Ceanothus Series with inclusion of the Interior Live Oak ies is seen in *A*. The predominant Series is chamise with associated manzanita species. The foreground is dominated by the Chamise/Pointleaf Manzanita sociation *(B)*. Classification systems that use a broader descriptive level than ours might view the vegetation in *A* as a single community; the visual formity of the landscape cover will relegate most of the vegetation to a single "type" under some vegetation mapping systems. Most of the shrubs in *A* are n 2 to 3 feet (0.6 to 1 m) in height.

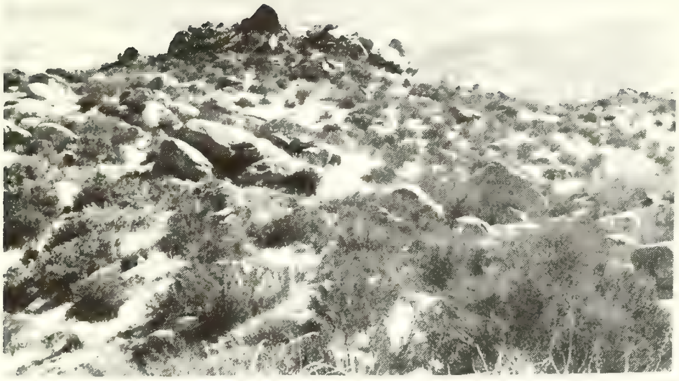


Figure 25—A Chamise/Wild Oats Association on a rocky site near Banning, California. Slow growth of the shrubs has been a factor contributing to the persistence of this two-layered Association. An admixture of ceanothus appears in the middle ground.

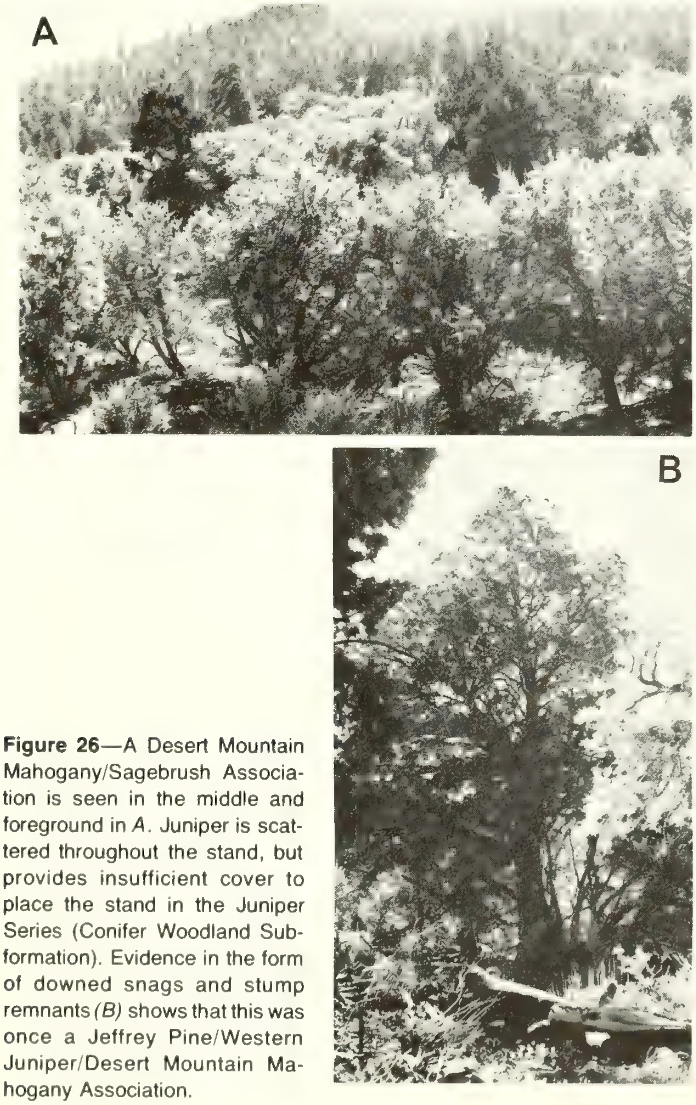


Figure 26—A Desert Mountain Mahogany/Sagebrush Association is seen in the middle and foreground in *A*. Juniper is scattered throughout the stand, but provides insufficient cover to place the stand in the Juniper Series (Conifer Woodland Subformation). Evidence in the form of downed snags and stump remnants *(B)* shows that this was once a Jeffrey Pine/Western Juniper/Desert Mountain Mahogany Association.

Ceanothus Series

Vegetation: Ceanothus species are the dominant overstory vegetation. This Series can produce open stands when mature since *Ceanothus* shrubs are rather short lived. Fifty-year-old stands may have herbaceous vegetation interspersed with shrubs. *Ceanothus* is one of the chaparral shrubs with ability to fix nitrogen in soils.

Distribution: Ceanothus spp. occur from southwestern Oregon to Baja California, on both inland and coastal slopes.

Chamise Series

Vegetation: Adenostoma fasciculatum is the dominant overstory shrub. The mature vegetation is dense and excludes any herbaceous understory. This Series occupies the hottest and driest of chaparral sites (*fig. 25*).

Distribution: Chamise covers more land in California than any other single Series. It exists from the north Coast Ranges south to Baja California.

Bush Chinquapin Series

Vegetation: Chrysolepis sempervirens is the dominant overstory species, forming pure dense stands at high elevations.

Distribution: The Bush Chinquapin Series occurs from southern Oregon south to the San Jacinto Mountains.

Mountain Mahogany Series *(fig. 26)*

Vegetation: Cercocarpus betuloides, C. traskae, C. ledifolius, or *C. minutiflora* are the dominant overstory species. This Series occupies a more mesic habitat than many chaparral shrubs. *Cercocarpus* has the ability to fix soil nitrogen.

Distribution: Cercocarpus betuloides is found from Oregon through cismontane California to Baja California; *C. minutiflorus* from San Diego County south to Baja California; and *C. traskae* only on Santa Catalina Island. *C. ledifolius* occurs on slopes adjacent to the desert, and extends westward, through the Tehachapi Mountains, to the Mt. Pinos area.

Manzanita Series

Vegetation: Arctostaphylos species are the dominant overstory. Mature stands are very dense and impenetrable, and the form varies from low mats to small trees. This Series comprises higher elevation chaparral and is sometimes referred to as ''cold chaparral.''

Distribution: Manzanita occurs from southern Oregon to Baja California and east through central Arizona.

Scrub Oak Series

Vegetation: Dominant overstory is *Quercus dumosa, Q. turbinella, Q. macdonaldii, Q. tomentella,* or *Q. dunnii* in dense stands with no understory in mature stands. Many other shrub species may be associated with the Scrub Oak Series.

Distribution: Quercus dunnii is limited in distribution, occurring in San Luis Obispo County and in isolated stands to Baja California. *Q. dumosa* ranges from Baja California throughout the State. *Q. turbinella* ranges from transmontane California east to Texas. *Q. macdonaldii* and *Q. tomentella* are restricted to the Channel Islands.

Prunus Series *(fig. 27)*

Vegetation: Dominant overstory is Catalina cherry (*Prunus lyonii*), bitter cherry (*P. emarginata*), or desert apricot (*P. fremontii*). Catalina cherry and bitter cherry are evergreen and y grow into small trees in optimum habitat. Desert apricot is rought-deciduous shrub.

Distribution: Catalina cherry occupies canyons on the annel Islands and bitter cherry occupies rocky ridges or yons from San Diego County north. Desert apricot is found slopes above 4000 feet (1219.2 m) at the western edge of California Sonoran Desert and extends south into Baja ifornia.

Redshank Series *(fig. 28)*

Vegetation: Adenostoma sparsifolium is the dominant over- ry shrub. Individual shrubs have open crowns and therefore ierbaceous understory may be present, even in mature nds.

Distribution: Redshank exists from San Luis Obispo unty south along the coast to Los Angeles County, then fts in distribution inland to the Peninsular Mountain ranges, owing them south into Baja California.

Sumac Series

Vegetation: Rhus laurina, R. ovata, or *R. integrifolia* are minant overstory species. Sumacs are more often compo- nts of Scrub Oak or Manzanita Series than a dominant cies. However, coastal and island slopes may support al- st pure stands of sumac.

Distribution: Rhus laurina and *R. integrifolia* occur near the st from Santa Barbara County south to Baja California and the Channel Islands. *R. ovata* occurs away from the coast to ert edges throughout southern California.

Toyon Series

Vegetation: Dominant overstory is *Heteromeles arbutifolia* h other chaparral shrubs.

Distribution: Toyon grows on coastal foothills north to mboldt County and on the Channel Islands.

t Chaparral Subformation *(fig. 29)*

Vegetation: Soft Chaparral is dominated by evergreen or iduous soft shrubs (shrub forms with little woody tissue) stly less than 5 feet (1.5 m) tall. Shrub crown cover ranges n 25 to 100 percent, often with grasses and forbs codomin- Trees, if present, have a crown cover of less than 25 cent.

Distribution: Soft Chaparral is present at lower elevations low the Chaparral Subformation [*fig. 30*]), throughout thern California, extending north along the coast and Cen- Valley.

eries within the Soft Chaparral Formation are named for dominant species present or the species representing 60 cent of the total overstory cover. Grasses and forbs are ally present in all phases.

Baccharis Series

Vegetation: The dominant shrub overstory is *Baccharis* spp. *charis pilularis* is common on coastal foothills. Riparian cies are *B. glutinosa, B. sergiloides,* and *B. sarathroides,* latter two being confined to desert riparian habitats.

Distribution: Baccharis pilularis occurs from Sonoma nty southward through central and coastal California to Diego County, including the Channel Islands. The ripa- species occur from Inyo County south to Mexico and east Texas.

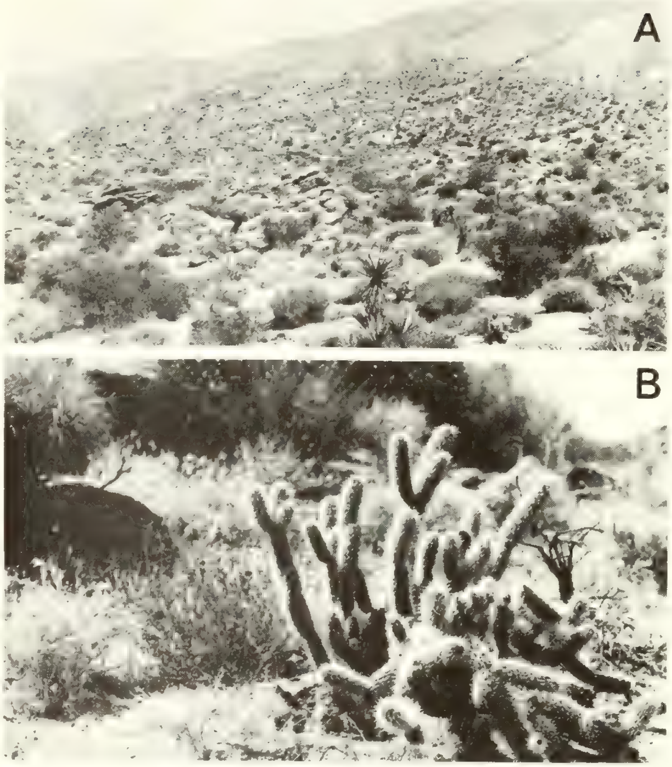


Figure 27—A Desert Apricot/Mojave Yucca/Silver Cholla Association is seen in the middle and foreground in *A*. Although plant density is lower than in communities found on more mesic habitats, the number of associated species is relatively high. An interior view of this stand shows the dominance of buckwheat, bladder-sage, and silver cholla *(B)*.

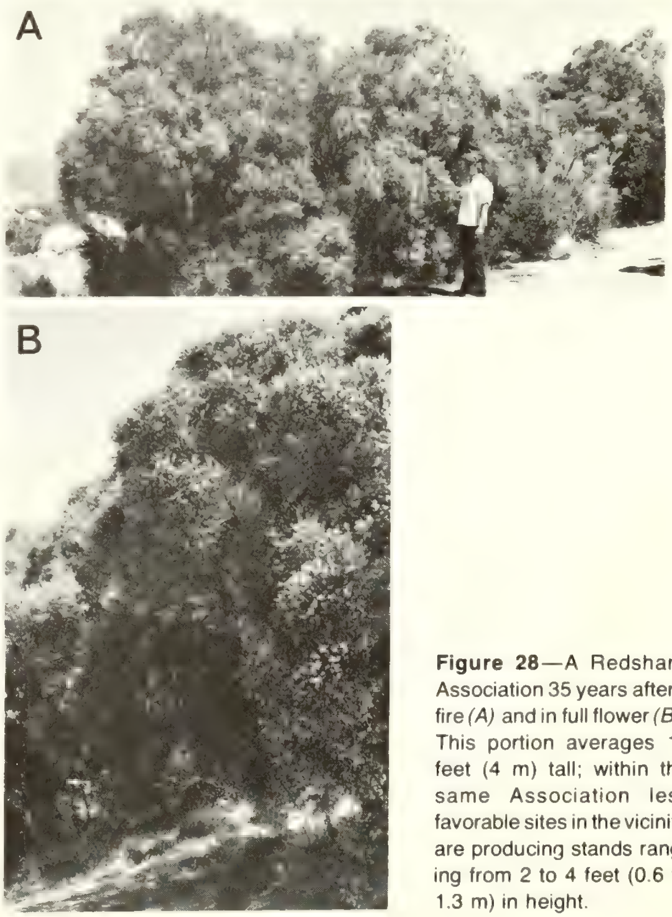


Figure 28—A Redshank Association 35 years after a fire *(A)* and in full flower *(B)*. This portion averages 12 feet (4 m) tall; within the same Association less favorable sites in the vicinity are producing stands ranging from 2 to 4 feet (0.6 to 1.3 m) in height.

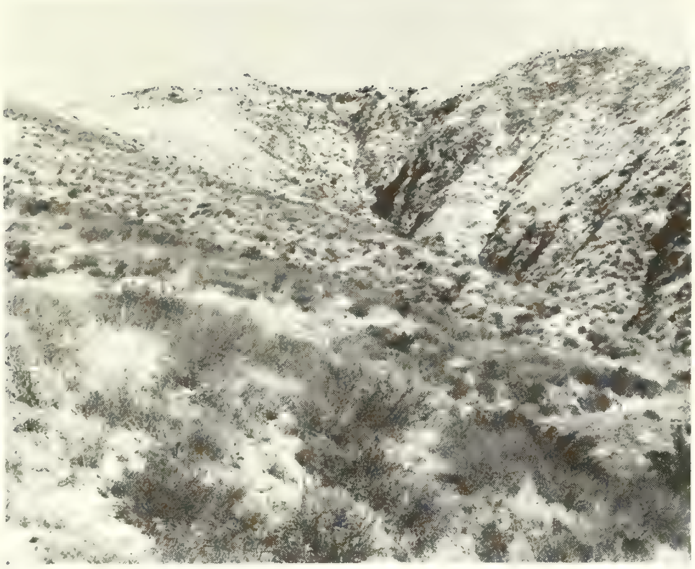


Figure 29—Associations within the Soft Chaparral Subformation occur in a mosaic pattern that reflects moisture availability and heat load.

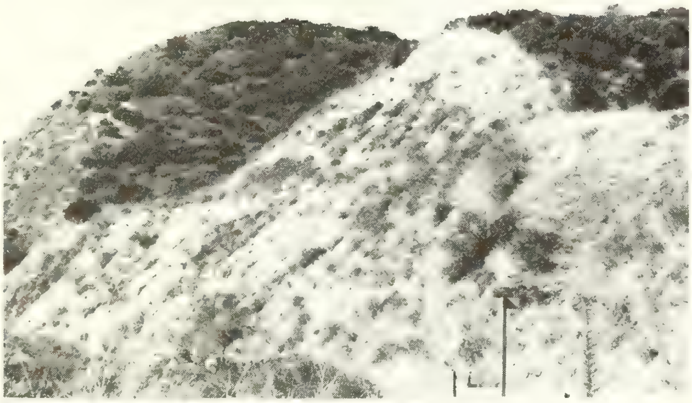


Figure 30—Soft Chaparral often invades cutbanks in the interface zone between habitats of the Soft Chaparral and the Chaparral Subformations. Variation in plant density within an Association can be seen along this cutbank.

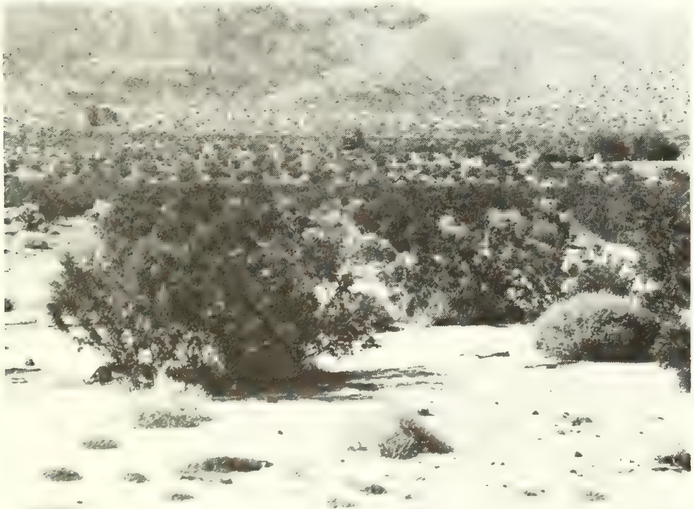


Figure 31—The Creosote/Burrobush Association represents the Woody Shrub Subformation in this interface between Low Desert Valley and High Desert Valley climate regions.

California Buckwheat Series

Vegetation: Eriogonum fasciculatum is the dominant overstory shrub, with herbaceous understory.

Distribution: California Buckwheat Series is found at low elevations in mountain foothills and valleys from Santa Clara County south to Baja California. Varieties of California buckwheat can occur at high elevations as an understory component in several Forest or Woodland Series.

Coastal Sagebrush Series

Vegetation: Artemisia californica is the dominant shrub overstory with a grass/forb understory. *Yucca whipplei* is sometimes codominant in this Series, particularly in Santa Barbara County.

Distribution: This Series is present on low-elevation coastal foothills and interior valleys from Baja California north to San Francisco Bay including the Channel Islands.

Croton Series

Vegetation: Croton wigginsii is the dominant vegetation covering desert sand dunes.

Distribution: Croton Series is restricted to the dunes of the California Sonoran Desert in southeastern California and into Mexico.

Encelia Series

Vegetation: Encelia farinosa or *E. californica* are dominant overstory shrubs with a herbaceous understory.

Distribution: The Encelia Series occurs from Santa Barbara and Inyo Counties south to Baja California.

Lupine Series

Vegetation: Lupinus arboreus or *L. chamissonis* form the dominant overstory, with other soft shrubs and herbaceous species in the understory.

Distribution: Lupine shrubs range from Ventura County north along the California coastline. The Lupine Series occurs only on coastal bluffs.

Rabbitbrush Series

Vegetation: Chrysothamnus nauseosus or other *Chrysothamnus* species form the dominant overstory, with a grass and herbaceous understory.

Distribution: Rabbitbrush ranges throughout the Great Basin into western and southwestern California. There are many varieties of *Chrysothamnus nauseosus* from low elevations to above 9000 feet (2743.2 m).

Salvia Series

Vegetation: Purple sage (*Salvia leucophylla*), black sage (*Salvia mellifera*), or white sage (*Salvia apiana*) are dominant overstory species with a herbaceous understory. The Salvia Series covers coastal and inland foothills at low elevations.

Distribution: Salvia mellifera ranges from Contra Costa County south to Baja California and the Channel Islands. *S. leucophylla* ranges from San Luis Obispo County to Orange County; *S. apiana* ranges from Santa Barbara County to Baja California.

Woody Shrub Subformation

Arrowweed Series

Vegetation: Pluchea sericea is the dominant overstory vegetation in seeps or marshes and following canals.

istribution: Pluchea sericea occurs from Santa Barbara nty throughout cismontane southern California and east to as. The Series is common along the Colorado River and ation canals in the California Sonoran Desert.

lackbush Series

egetation: Coleogyne ramosissima is the dominant over- y shrub. Blackbush is drought-deciduous. Associated spe- vary, but usually include *Ephedra* spp., *Chrysothamnus* , and California buckwheat (*Eriogonum fasciculatum*).

istribution: Blackbush occurs from the southern Mojave ert north and east through the Great Basin.

atclaw Series

egetation: Acacia greggii, a winter-deciduous shrub, is dominant overstory with subshrubs in the understory. The tat in California often follows washes or canyons where e soil moisture is available.

istribution: Catclaw is found in the southern Mojave Des- throughout the California Sonoran Desert, south to ico, and east to Texas.

reosote Bush Series

egetation: Larrea tridentata, an evergreen shrub, is the inant overstory. Understory plants vary, but burrobush *brosia dumosa*) is most often codominant in California *31*).

istribution: Creosote is found throughout both deserts, ing south from Inyo County into Mexico and east into as. *Larrea* spp. also occur in South America.

reasewood Series

egetation: Sarcobatus vermiculatus is the dominant shrub urring with saltbush (*Atriplex* spp.) on strongly alkaline, e soils.

istribution: Greasewood occurs throughout the Mojave ert north to Washington and east throughout the Great n in suitable habitats.

cotillo Series

egetation: Fouquieria splendens, a drought-deciduous b, is the dominant overstory, with subshrubs and stem ulents present in the understory. The substrate is usually y.

istribution: Ocotillo occurs from the southeastern Mojave ert through the Sonoran Desert to Texas and Mexico.

ild Rose Series *(fig. 32)*

egetation: Rosa californica, R. gymnocarpa, or *R. wood-* re dominant, forming thickets in moist soil.

istribution: Rosa species occur throughout the West in y vegetation types. The Series usually occurs below 6000 (1828.8 m) elevation in cismontane southern California.

agebrush Series *(fig. 33)*

egetation: Artemisia tridentata is the most common domi- shrub, although *A. nova, A. arbuscula,* or *A. rothrockii* also form the dominant overstory. These are all evergreen bs and may be associated with perennial grasses.

istribution: The Sagebrush Series is found from the ntains of southern California north to Oregon and ughout the Great Basin. The Series occurs at 7000 feet 3.6 m) elevation interspersed with Series of the Closed st or Woodland Formations, as well as in the Mojave ert.

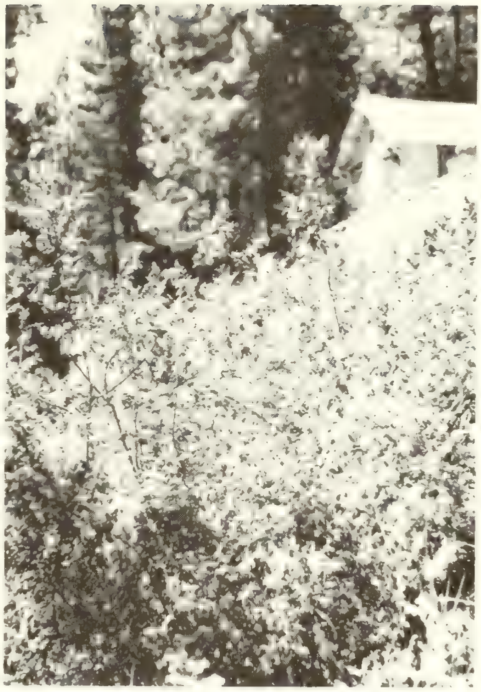


Figure 32—An element of the Rose Series (Woody Shrub Subformation) occurring in a moist opening in a landscape cover dominated by the Closed Forest Formation—near Big Bear Lake, California.

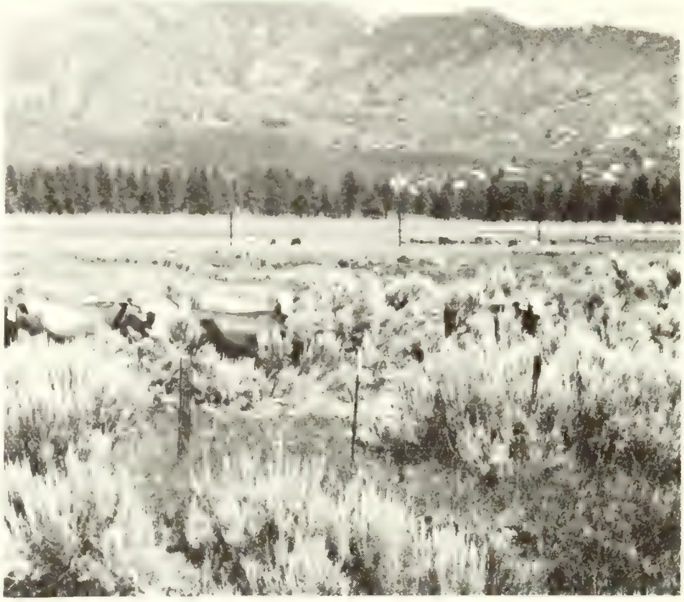


Figure 33—Portions of this range being used by cattle belong to the Sagebrush Series of the Woody Shrub Subformation. Jeffrey pine (Closed Forest Formation) flanks the Herbaceous Formation that occurs in the pastureland, while a mosaic comprised of elements of the Shrub Formation carries upward on the far slopes to the Closed Forest Formation that occurs along the ridge.

Saltbush Series

Vegetation: Dominant overstory may be *Atriplex confertifolia, A. polycarpa, A. canescens,* and other *Atriplex* spp. Saltbush species may be evergreen or drought-deciduous shrubs occurring on alkaline and saline soils.

Distribution: The Saltbush Series occurs in both California deserts, north to eastern Oregon, and throughout the Great Basin.

Succulent Shrub Subformation

Agave Series

Vegetation: Agave deserti is the dominant species, with a highly diverse group of associated species. The Agave Series occurs on foothills between the Desert Shrub and Chaparral Formations.

Distribution: Agave occurs in the southern Mojave Desert and western California Sonoran Desert.

Iodine Bush Series

Vegetation: Allenrolfea occidentalis, a low-growing succulent shrub, is the dominant species occurring with saltbush (*Atriplex* spp.) and seep-weed (*Suaeda* spp.). Soils are wet, strongly alkaline, and saline.

Distribution: Iodine bush occurs in the Mojave Desert, Central Valley north to Oregon, east to Utah, and south into Mexico.

Opuntia Series *(fig. 34)*

Vegetation: Dominant overstory is cholla (*Opuntia bigelovii* and other *Opuntia* species), or prickly pear (*Opuntia* spp.) occurring with barrel (*Ferocactus acanthodes*) and hedgehog (*Echinocereus* spp.) cacti. *Opuntia* reproduces vegetatively when joints fall to the ground. The species are more often associates of other Series than dominant stands.

Distribution: Opuntia bigelovii occurs from the southeast Mojave Desert throughout the Sonoran Desert into Mexico. *O. littoralis* is a succulent-stemmed, prostrate shrub that occurs within 50 miles (80.4 km) of the coastline from Santa Barbara County south to Baja California; varieties of the species occur up to 7000 feet (213 m) as a component of several other Series.

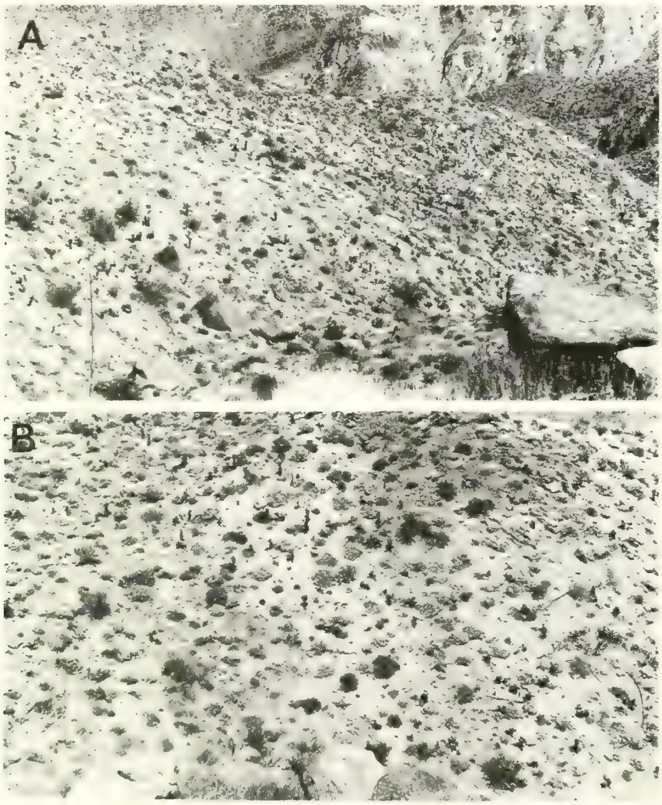


Figure 34—The Cholla Series dominates the middle and foreground of this scene *(A)*. A closeup shows the sparse occurrence of dominant and associated species, as well as the patterns of oxidation found on the rock and soil surfaces in desert environments *(B)*.

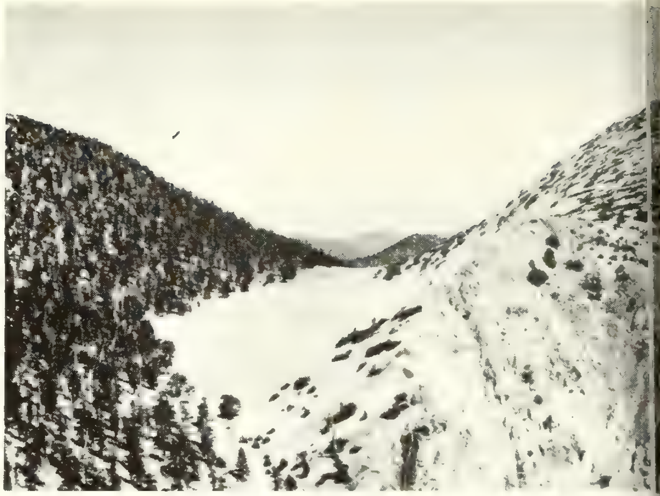


Figure 35—The Dwarf Shrub Formation is found in the remnants of th glacial tarn. To the left of the tarn is an element of the Lodgepole Pi Series, and krummholtz limber pine can be seen on the right. The cushio Plant Subformation is the grey texture in the bottom of the tarn.

Dwarf Shrub Formation

Vegetation: The shrubs that dominate this Formation are less than 1½ feet (½ m) in height at maturity. The Cushion Plant Subformation is dominated by nonsucculent (stem or leaves) dwarf shrubs; in southern California, only one Series is currently recognized with this Subformation. The Succulent Dwarf Shrub Subformation contains all Series dominated by succulent dwarf shrubs; two Series are currently recognized for this Subformation in southern California.

Distribution: The Dwarf Shrub Formation has worldwide distribution. It occurs in a wide range of habitats, from alpine environments above timberline to alkaline desert environments below sea level.

Suggested Phases are:

Cover
1. <2
2. 2-10
3. 10-25
4. 25-50
5. 50-70
6. >70

Cushion Plant Subformation

Buckwheat Series

Vegetation: Dominant cover is *Eriogonum* spp. and other cushion plants. This Series is sometimes called "barren" because of the sparse vegetation cover (*fig. 35*).

istribution: The Buckwheat Series occurs throughout the st on high mountain peaks above tree line. In southern ifornia, this Series is interspersed among subalpine forests imber Pine or Bristlecone Pine Series.

culent Dwarf Shrub Subformation

ickleweed Series

egetation: Salicornia spp. is the dominant vegetation oc- ring in saltwater marshes. Most species are winter dormant.

istribution: Pickleweed occurs in coastal salt marshes and und inland saltwater lakes such as the Salton Sea and Mono e.

uaeda Series

egetation: Dominant overstory is *Suaeda californica, S. icosa,* or *S. torreyana,* all succulent shrubs or subshrubs upying salt marshes or alkaline marshes.

istribution: The Suaeda Series is present worldwide. *eda californica* occurs along the coast from San Francisco y to Baja California. *S. torreyana* ranges from eastern gon through inland California east to Texas and into xico. *S. fruticosa* extends from the San Joaquin Valley th to Mexico, but is also found in West Indies, Europe, a, and Africa (McMinn 1939).

rbaceous Formation

egetation: The Herbaceous Formation is dominated by sses, sedges, rushes, forbs, or freshwater aquatic plants. At st 2 percent of the land surface has an herbaceous cover. If ubs are present, they contribute less than 25 percent crown er (*fig. 36*). Grasslands, wet meadows, marshes, and vege- on in shallow freshwater ponds are all part of the Herbace- Formation (*fig. 37*). Herbaceous coastal strand plants and nts of coastal salt marshes are included. However, this tem makes no attempt to cover marine or intertidal zones.

istribution: The Herbaceous Formation occurs worldwide ppropriate habitats. Four Subformations of the Herbaceous mation are recognized; Grasses and Grasslike Plants aminoid), Forb, Aquatic, and Cryptogam Subformations.

uggested Phases are:

	Cover	
Productivity	*Living Vegetation*	*Litter*
Pounds per	1. <2	1. <25
acre	2. 2-25	2. 25-50
(optional)	3. 25-50	3. >50
	4. 50-70	
	5. >70	

minoid Subformation

he Series are named for the dominant genus or species, ally that plant comprising more than 60 percent of the total aceous cover (*fig. 38*).

romegrass Series

egetation: Dominant vegetation is *Bromus rubens, B. drus, B. mollis,* or *B. tectorum,* all introduced species.

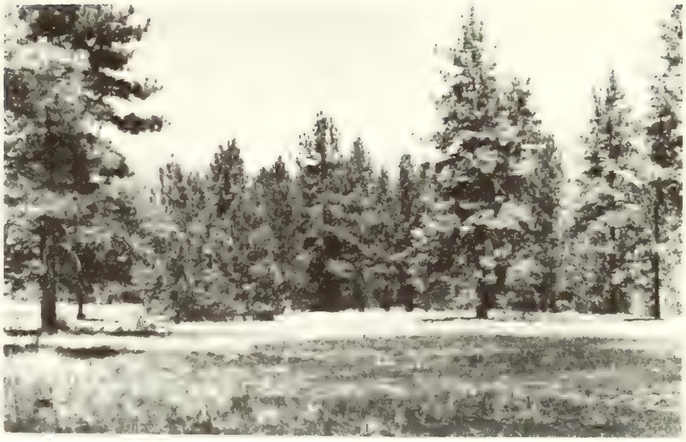


Figure 36—The Herbaceous Formation in the foreground is represented by the Bromegrass and the Wiregrass Series. Evidence indicates that the Wild Rye Series is the most immediate potential vegetation for the entire stand; whether the change to this Series occurs or not will depend upon future use of the range and disturbance.

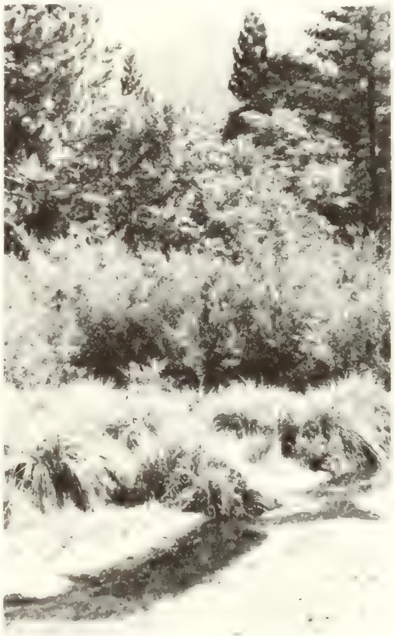


Figure 37—A temporarily drained lake provided an opportunity to observe the Graminoid Subformation in a normally inaccessible riparian zone. Distinct zones occupied by the Herbaceous, Shrub, and Woodland Formations can be seen. The Closed Forest Formation occurs in the background.

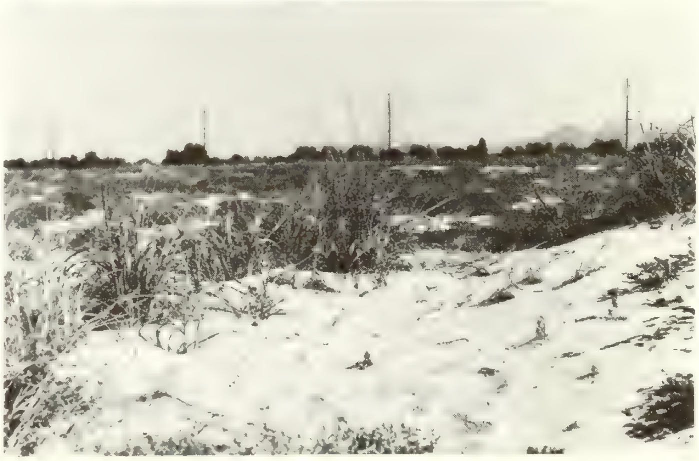


Figure 38—Sand dunes provide a unique habitat for the Graminoid Subformation in this desert environment; the grass is *Panicum urvilleanum*—a possible requirement for a Panicum Series. The Forb Subformation dominates the cover adjacent to the dunes.

Distribution: Introduced *Bromus* species occur throughout the West and are now considered to be climax stands in much of California's Central Valley (Heady 1977).

Bulrush Series

Vegetation: Dominant vegetation is *Scirpus* species. Bulrushes are rooted in mud beneath shallow water.

Distribution: The Bulrush Series occurs worldwide in shallow saltwater marshes.

Cattail Series

Vegetation: Dominant vegetation is *Typha* species. Cattails are rooted in mud beneath shallow water.

Distribution: The Cattail Series occurs worldwide in shallow freshwater marshes.

Cordgrass Series

Vegetation: Dominant vegetation is *Spartina foliosa* or *S. gracilis*, coarse perennial grasses from stout creeping rootstock.

Distribution: Spartina occurs in coastal salt marshes or interior alkaline meadows throughout North America.

Fescue Series

Vegetation: Dominant vegetation is *Festuca megalura*, *F. myuros* (introduced from Europe), *F. octoflora*, and other *Festuca* species mixed with other annual grasses.

Distribution: Festuca species occur throughout the West from British Columbia to Baja California.

Galleta Grass Series

Vegetation: Dominant vegetation is *Hilaria rigida*, *H. jamesii*, or *H. belangeri*.

Distribution: Galleta grass occurs throughout the western deserts. *Hilaria rigida* is found below 4000 feet (1219.2 m) and *H. jamesii* occurs from 4000 to 7500 feet (1219.2 to 2286 m). *H. belangeri* is reported from extreme southeastern California and through Arizona to Sonora, Mexico.

Muhlenbergia Series

Vegetation: Dominant vegetation is *Muhlenbergia rigens*, a perennial bunchgrass or other *Muhlenbergia* species.

Distribution: Muhlenbergia rigens occurs in seasonally wet meadows throughout California. Other *Muhlenbergia* species occupy moist alkaline to dry habitats throughout North America.

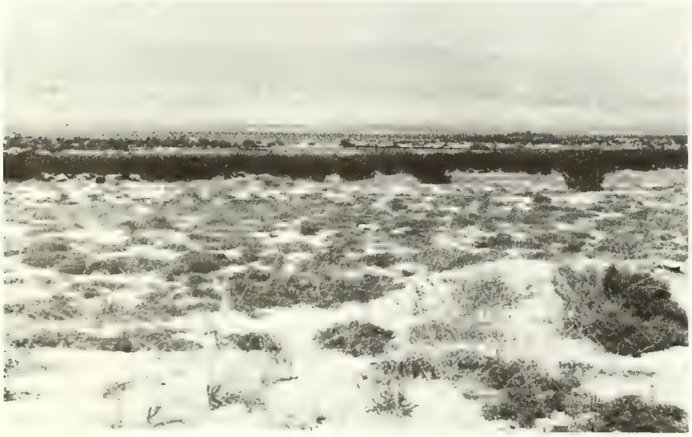


Figure 39—The Forb Subformation dominates most of this desert valley. The Plicate Coldenia/Desert Dichoria Association dominates the middle ground. Just beyond it is a Plicate Coldenia/Desert Dichoria (Creosote Bush) Association.

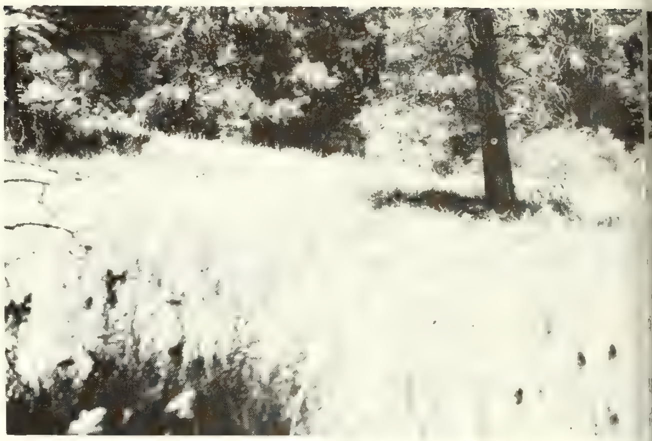


Figure 40—The Goldenrod Series occurs in an opening in a Jeffrey p forest.

Needlegrass Series

Vegetation: Dominant vegetation is *Stipa pulchra*, *S. cernua*, *S. speciosa*, *S. coronatum*, or other *Stipa* species. All ar perennial bunchgrasses.

Distribution: Stipa species once covered extensive areas o California. Minor remnants occur today. The perennial grasslands of California have been largely replaced by introduce annual grasses and are now included in the Bromegrass Series

Wild Oats Series

Vegetation: Dominant vegetation is *Avena barbata* or *A fatua*, both introduced species.

Distribution: Avena species occur throughout Californi and is sometimes considered to be climax in the Central Valle (Heady 1977).

Ricegrass Series

Vegetation: Dominant vegetation is *Oryzopsis hymenoides* a perennial bunchgrass.

Distribution: Oryzopsis hymenoides occurs throughou Western North America, from the desert to 11,000 fee (3352.8 m) elevation.

Wild Rye Series

Vegetation: Dominant vegetation is *Elymus glaucus*, *E. triticoides*, or other *Elymus* species.

Distribution: Elymus species occur throughout the West up to 10,500 feet (3200.4 m). *Elymus triticoides* is restricted to moist alkaline habitats.

Sacaton Series

Vegetation: Dominant vegetation is *Sporobolus airoides*, a densely-tufted perennial.

Distribution: Sporobolus airoides occurs in dominant stands throughout the West in river bottoms or moist alkaline places.

Saltgrass Series

Vegetation: Dominant vegetation is *Distichlis spicata* in dense rhizomatous mats. Saltgrass is a dioecious perennial frequently forming all male or all female clones which reproduce vegetatively.

Distribution: Saltgrass occurs in dominant stands throughout much of North America, growing in coastal salt marshes or inland alkaline soils.

edge Series

egetation: Dominant vegetation is sedge members of the us *Carex* or *Cyperus*.

istribution: Sedges are grasslike plants occurring ldwide, usually in meadows or seasonally wet habitats.

Viregrass Series

egetation: Dominant vegetation is *Juncus* species or *ıla* species.

istribution: Juncus and *Luzula* species are grasslike plants urring worldwide in moist meadows or marshy habitats.

Subformation

eries in this Subformation are varied, and are named for the ies comprising 60 percent or more of the herbaceous er. Only two examples are described here. Others may be ed as inventories reveal what exists. Care must be taken to sify *only* those vegetation types with forbs as the relatively nanent vegetation type within the Forb Subformation.

mbrosia Series

egetation: Ambrosia chamissonis and other *Ambrosia* spp. the dominant overstory with a herbaceous understory.

istribution: Ambrosia chamissonis is a coastal strand spe- occurring in scattered locations along the southern Cali- ia coastline north to British Columbia and on the Channel ıds.

oldenia Series *(fig. 39)*

egetation: Coldenia species form the dominant vegetation, associated with other herbaceous plants.

istribution: The Series occurs throughout the Western ed States in desert and Great Basin environments.

oldenrod Series *(fig. 40)*

egetation: Dominant vegetation is *Solidago californica, S. inis, S. occidentalis,* or *S. spectabilis.*

istribution: Solidago species occur from lower California regon, and from the coast to the desert. Habitats vary with ies.

lustard Series

egetation: Dominant vegetation is *Brassica* or *Sisymbrium* ies, annual introduced plants of the mustard family.

Distribution: Mustards occur worldwide and may occur in relatively permanent dominant stands as a result of man's activities.

Wyethia Series

Vegetation: Dominant vegetation is *Wyethia ovata,* a coarse perennial with a thick taproot.

Distribution: Wyethia ovata occurs from the southern Sierra Nevada to Baja California, occasionally occurring in dominant stands interspersed with grasslands or as islands in open woodlands.

re 41—The Aquatic Subformation is represented here by water tweed (*Polygonum amphibium*), another potential candidate for s status in the Vegetation Classification System.

Aquatic Subformation *(fig. 41)*

Series in this Subformation include those whose dominant species require water for structural support. Several examples are described and when comprehensive inventories are done, the list of Series in the Aquatic Subformation may increase (*fig. 42*).

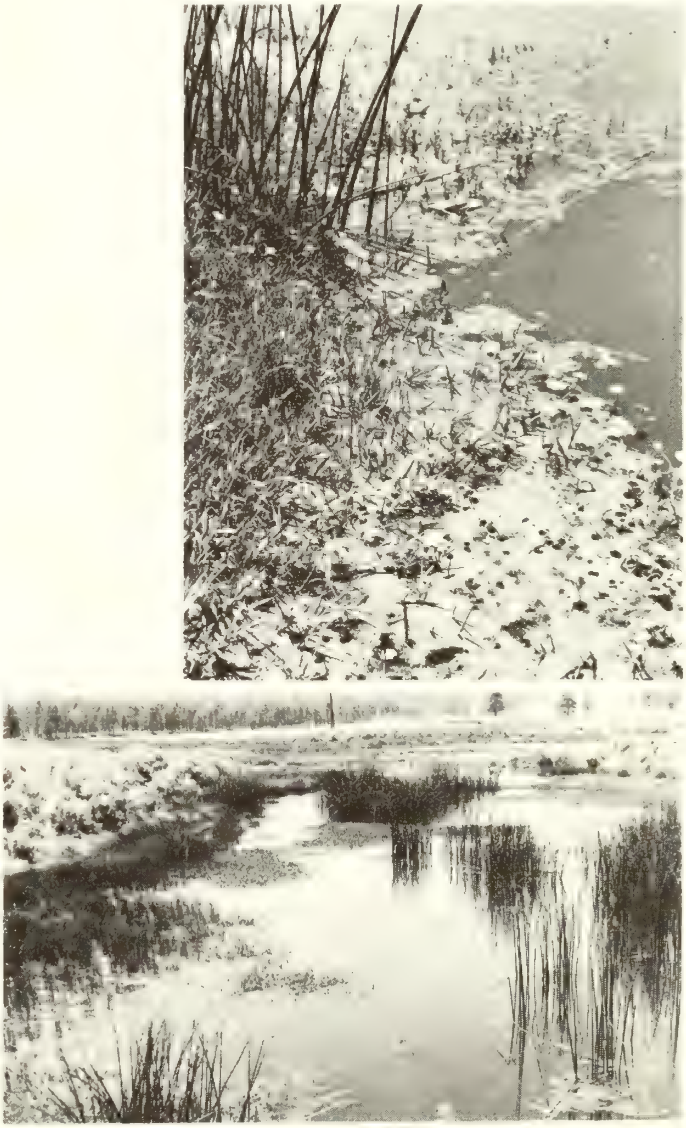


Figure 42—Elements of the Aquatic Subformation often require more than a cursory above-water examination to determine their classification status. The aquatic element of this river community (below) can be comprised of one or two distinct communities or can be an "understory" to the *Scirpus. Ludwigia repens* and *Hydrocotyle* species, both aquatics, are found here (above).

Pondweed Series

Vegetation: Dominant vegetation is *Potamogeton* species, submerged plants, barely reaching the water surface. .

Distribution: Potamogetons occur worldwide in quiet freshwaters.

Water Hyacinth Series

Vegetation: Dominant vegetation is *Eichornia crassipes,* a submerged and floating aquatic.

Distribution: Eichornia is a native of tropical America which has become naturalized in some of southern California's freshwater systems.

Water Milfoil Series *(fig. 43)*

Vegetation: Dominant vegetation is *Myriophyllum exalbescens,* a submerged aquatic floating from stems up to 3.3 fe (1 m) long and rooted in the shallow lake bottom.

Distribution: Myriophyllum occurs in quiet water throug out North America.

Cryptogam Subformation

Series within the Cryptogam Subformation are poorly rep resented in California, whereas they cover vast expanses c land in the arctic tundra. Alpine areas lacking overstory vege tation are designated barren in some classification schemes However, as inventories are completed, some of them may b named for their dominant cryptogam genera. Mosses, lichens and ferns are included in this Subformation (*fig. 44*).

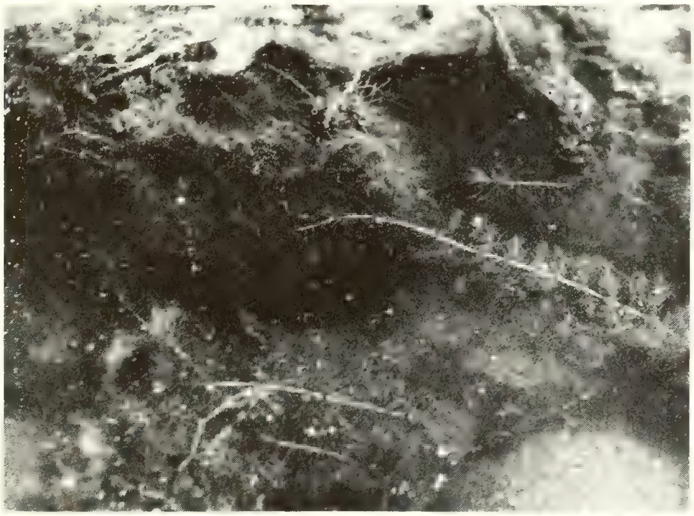


Figure 43—The Water Milfoil Series (Aquatic Subformation) is a common inhabitant of quiet waters in southern California. Where nutrient levels are high, this series can become troublesome to human activities.

Figure 44—The Fern Series (Pteridium aquilinum) is a common eleme of the Cryptogam Subformation in southern California.

'PENDIX

Climate Regions of Southern California

e climate regions adapted from Almquist's study are
ned as follows:[5]

stal

he westernmost portion of southern California, extending
nd to the coastal foothills. Maritime influence dominates,
even seasonal temperatures averaging 50° F (10° C) in
er and 67° F (19.4° C) in summer,[9] and little daily fluctua-
. Average humidity is above 50 percent and precipitation
e form of winter rains ranges from 6 inches (152 mm) in
south to 60 inches (1524 mm) in the coastal ranges of the
h.

rior Valley

he gentle undulating terrain from the coastal foothills to
nterior mountain foothills, up to 2500 feet (762 m) eleva-
at the eastern limit. Temperature extremes can range from
w freezing in the winter to above 100° F (37.8° C) in the
mer, with an average of 55° F (12.8° C) in winter and
F (23.9° C) in summer. Relative humidity averages 15 to
ercent. Precipitation occurs primarily as winter rains,
aging 8 to 13 inches (20.3 to 330.2 mm) per year.

sition

region characterized by higher precipitation (12 to
nches [304.8 to 508 mm] per year) and lower average
peratures (51° F [10.6° C] in winter, 72° F [22.2° C] in
mer) than the interior valley. It occurs on the coastal
nontane) side of the mountains. There are extreme eleva-
al differences, with lower limits ranging from 500 to 2500
(152.4 to 762 m), and usually an upper limit of 4500 feet
1.6 m).

Montane

Mountainous areas between 4500 and 9000 feet (1371 and 2833 m) on the coastal (cismontane) side and between 6500 and 9000 feet (1981 and 2743 m) on the desert (transmontane) side. Precipitation from 15 to 40 inches (254 to 1016 mm) with an average of 25 inches (635 mm) per year. Snow is common at higher elevations and some summer rainfall (5 to 7 inches) (127 to 177 mm) occurs. In winter, average temperature is 38° F (3.3° C), in summer, 62° F (16.7° C).

High Montane

Mountainous areas between 9000 and 10,500 feet (2743 and 3200 m). Precipitation is mainly in the form of snow. Average temperatures are lower than those in the montane region.

Alpine

All mountainous regions above 10,500 feet (3200 m). Average temperatures are lower than in the high montane region, snow pack remains longer, and strong winds are common.

Desert Transition

Areas on the desert (transmontane) side of the mountains between 3500 and 6500 feet (1066 and 1981 m) elevation. Precipitation generally occurs in the winter with some snow, and averages 6 to 10 inches (152 to 254 mm) per year. Average temperatures are 50° F (10° C) in winter and 70° F (21.1° C) in summer.

High Desert Valley

Primarily, the Mojave Desert and adjacent mountain slopes up to 3500 feet (1066 m). Rainfall is generally less than 6 inches (152 mm) per year. Little weather data are available.

Low Desert Valley[10]

The California Sonora Desert and adjacent slopes up to 3500 feet (1066 m). This region is somewhat influenced by the Gulf Coast air mass, and therefore receives more summer rainfall than the high desert. Daily temperature fluctuations can be extreme, with highs up to 120° F (48.9° C). Rainfall is less than 4 inches (101 mm) per year. Again, little weather data are available.

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s used here, summer months are considered May through October,
r months November through April.

[10] The lowest elevations in this region are lower than any in the High Desert Valley region; the interface between the two is difficult to define.

B. Species Index

Abies bracteata 12
A. concolor 12, 14
Acacia greggii 23
Acer macrophyllum 15
Adenostoma fasciculatum 20
A. sparsifolium 21
Aesculus californica 16
Agave deserti 24
Alder 14
Allenrolfea occidentalis 24
Alnus rhombifolia 14
A. rubra 14
Ambrosia chamissonis 27
A. dumosa 23
Arbutus menziesii 15
Arctostaphylos species 20
Arrowweed 22
Artemisia arbuscula 23
A. californica 22
A. nova 23
A. rothrockii 23
A. tridentata 23
Aspen 15
Atriplex canescens 24
A. confertifolia 24
A. polycarpa 24
Avena species 26
Baccaris glutinosa 21
B. pilularis 21
B. sarathroides 21
B. sergiloides 21
Bigcone Douglas-fir 12
Bigleaf Maple 15
Blackbush 23
Brassica species 27
Bromus species 25
Buckwheat, California 22, 23
Buckwheat species 25
Bulrush 26
Burrobush 23
Cactus, Barrel 24
  Cholla 24
  Hedgehog 24
  Prickly Pear 24
California Bay 15
California Buckeye 16
Calocedrus decurrens 14
Carex 27
Catclaw 23
Cattail 26
Ceanothus 20
Cercidium floridum 17
C. microphyllum 17
Cercocarpus betuloides 20
C. ledifolius 20
C. minutiflora 20
C. traskae 20
Chamise 20
Cherry, Bitter 21
  Catalina 21
Chilopsis linearis 18
Chinquapin, Bush 20
Chrysolepis sempervirens 20
Chrysothamnus species 22, 23
Coldenia 27
Coleogyne ramosissima 23
Conifer, Mixed 14
Cottonwood 16
Creosote Bush 23
Croton wigginsii 22
Cupressus abramsiana 12
C. forbesii 12
C. goveniana 12
C. macrocarpa 12
C. sargentii 12
C. stephensii 12
Cyperus species 27
Cypress 12
Dalea spinosa 18
Desert Apricot 20
Desert Broom 17
Desert Ironwood 17
Desert Lavender 17
Desert Willow 18
Distichlis spicata 26
Douglas-fir 12
Echinocereus species 24
Eichornia crassipes 28
Elymus glaucus 26
E. triticoides 26
Encelia californica 22
E. farinosa 22
Ephedra species 23
Eriogonum fasciculatum 22, 23
Eriogonum species 24
Eucalyptus species 15
Ferocactus acanthodes 24
Fescue 26
Festuca species 26
Fouquieria splendens 23
Goldenrod 27
Grass, Brome 25
  Cord 26
  Galleta 26
  Needle 26
  Rice 26
  Sacaton 26
  Salt 26
  Wild Oats 26
  Wild Rye 26
Greasewood 23
Heteromeles arbutifolia 21
Hilaria belangeri 26
H. jamesii 26

igida 26
tis emoryi 17
nse-cedar 14
ne Bush 24
nd Ironwood 15
ua Tree 18
cus species 27
per, California 16
tah 16
Vestern 12
perus californica 16
ccidentalis 12
steosperma 16
ea tridentata 23
ocarpus densiflorus 15
ine 22
inus arboreus 22
hamissonis 22
nothamnus floribundus 15
drone 15
nzanita 20
quite 17
foil 28
ntain Mahogany 20
lenbergia rigens 26
stard 27
iophyllum exalbescens 28
, Black 15
lue 17
anyon Live 15
oast Live 15
ngelmann 17
nterior Live 17
crub 20
alley 17
tillo 23
eya tesota 17
ntia bigelovii 24
ittoralis 24
zopsis hymenoides 26
n 18
Verde 17
enix species 18
leweed 25
, Bishop 12
ristlecone 13
oulter 13
igger 16
effrey 14
nobcone 13
imber 13
odgepole 13
lonterey 14
nyon 16
onderosa 14
ugar 14
orrey 14
s attenuata 13
P. contorta 13
P. coulteri 13
P. flexilis 13
P. jeffreyi 14
P. lambertiana 14
P. longaeva 13
P. monophylla 16
P. muricata 12
P. ponderosa 14
P. quadrifolia 16
P. radiata 14
P. sabiniana 16
P. torreyana 14
Platanus racemosa 18
Pluchea sericea 22
Pondweed 28
Populus fremontii 16
P. tremuloides 15
P. trichocarpa 16
Potamogeton species 28
Prosopis glandulosa var. *torreyana* 17
P. pubescens 17
Prunus emarginata 20
P. fremontii 20
P. lyonii 20
Pseudotsuga macrocarpa 12
P. menziesii 12
Quercus agrifolia 15
Q. chrysolepis 15
Q. douglasii 17
Q. dumosa 20
Q. dunnii 20
Q. engelmannii 17
Q. kelloggii 15
Q. lobata 17
Q. macdonaldii 20
Q. tomentella 20
Q. turbinella 20
Q. wislizenii 17
Rabbitbrush 22
Redshank 21
Redwood, Coast 14
Rhus integrifolia 21
R. laurina 21
R. ovata 21
Rosa species 23
Sage, Black 22
  Purple 22
  White 22
Sagebrush, Coastal 22
Sagebrush species 23
Salicornia species 25
Salix gooddingii 18
S. hindsiana 18
S. lasiolepis 18
Saltbush 24
Salt-cedar 18
Salvia apiana 22

S. leucophylla 22
S. mellifera 22
Santa Lucia Fir 12
Sarcobatus vermiculatus 23
Scirpus species 26
Sedge 27
Sequoia sempervirens 14
Sisymbrium species 27
Smoke Tree 18
Solidago species 27
Spartina species 26
Sporobolus airoides 26
Stipa species 26
Suaeda californica 25
S. fruticosa 25
S. torreyana 25
Sumac 21
Sycamore 18
Tamarix species 18
Tanoak 15
Toyon 21
Typha species 26
Umbellularia californica 14
Washingtonia filifera 18
Water Hyacinth 28
White Fir 12
Willow, Arroyo 18
  Black 18
  Sandbar 18
Wild Oats 26
Wild Rose 23
Wild Rye 26
Wiregrass 27
Wyethia ovata 27
Yucca brevifolia 18
Y. whipplei 22

C. Glossary

Annual plant—A plant which completes its life cycle within one year or one growing season.

Broadleaf—Refers to leaves that are *not* needlelike or scalelike and plants that are angiosperms. For this publication, trees and shrubs that are *not* conifers will be said to have broad leaves.

Bunch grass—A perennial grass which forms evenly spaced clumps, spreading by vegetative reproduction at the outer edge of the clump and dying at the center of old age. It does not form a closed sod.

Canopy—The aggregate of tree and shrub crowns that provide a broken layer of cover; most often used in reference to tree crowns that provide an "overhead" canopy.

Cismontane—This side of the mountains. For this publication, west of the main axis of the Sierra Nevada, Transverse, and Peninsular Mountain ranges, as opposed to the desert side.

Codominant—Refers to plants of different species that shar stand dominance in the overstory (see Dominant). Thi use of codominant is different from timber managemen usage referring to dominant individuals in a stand that ar slightly subordinate to a few individuals that hav achieved superior stature.

Conifer—A cone-bearing tree with evergreen needle or scale like leaves. Includes genus *Pinus, Calocedrus Juniperus, Cupressus,* etc.

Crown cover—The vertical projection of a tree or shrub crown perimeter to the ground.

Crown sprout—A form of vegetative reproduction. A new shoot from the main crown of a tree which has been damaged, as by fire.

Cryptogam—A group of primitive plants such as mosses club mosses, lichens, and ferns, which do not produce true flowers or seeds.

Cushion plant—A plant that forms a low-growing mat of vegetation which hugs the ground. Individual plants spread vegetatively at the outer edge of the mat, sometimes rooting at nodes or branch tips.

D.b.h.—Diameter at breast height. The diameter of a tree trunk at 4.5 feet (1.37 m) above the ground.

Deciduous plant—A plant which sheds its leaves, triggered by some environmental factor, such as temperature or water availability.

Density—The average number of individuals (plants) per unit of space.

Disjunct—Separate, noncontinuous; occurring in isolated, separate populations.

Dominant—Characteristic of plants within a system of vegetation, which by reason of size or numbers exert some controlling influence on the environment. For this publication, most numerous in the overstory.

Ecotone—A transition zone between two different types of dominant vegetation, containing components of each type.

Established tree—For this publication, a young tree with the crown rising above surrounding understory vegetation.

Evergreen—Refers to plants that do not generally shed their leaves in response to normal fluctuations in environmental conditions.

Forb—A broadleafed herbaceous plant.

Forest—Generally, an area of land covered by trees whose crowns are mostly touching. Because closed forests with interlocking crowns are rare in southern California, areas that grow trees with a crown cover of 60 percent or more are considered forests.

Grass—Herbaceous plants with narrow leaves in the family Poaceae.

Habitat—As an abstract concept, refers to that combination of environmental factors which provides suitable conditions for the existence of an organism or group of organisms; also, the concrete realization of such a combination in the field.

Herbaceous—Herblike or composed of herbs—plants with soft green leaves and no woody tissue.

Hydric—Characterized by considerable moisture.

mmholtz—A twisted, dwarfed, or prostrate growth habit of trees that is the result of severe environmental conditions.

r—Slightly decayed, nonliving plant parts scattered on the ground; duff.

ic—Characterized by moderately moist conditions.

rstory—The taller plants within a vegetation type, forming the upper layer of canopy cover.

nnial plant—A plant which lives for 2 years or more. Sometimes only the underground parts remain alive while the green herbaceous parts die back.

siognomy—The characteristic structure of vegetation, apart from land form.

t stands—Remnants of a vegetation type that once occupied an extensive area (or was present in scattered form over an extensive area), but has since become nearly extinct. This often results from shifts in the state of a given environmental factor or combination of factors.

rian—Pertaining to the bank or edge of a river, lake, stream, or subsurface water source within 10 feet (3.05 m) of the ground surface.

sprouts—Vegetative growth (branches) emerging from a basal root burl or root nodes. Common in chaparral shrubs.

n—A grasslike plant in the family Juncaceae.

nnah—A grassland containing scattered trees or shrubs.

b—Vegetation consisting mainly of shrubs or stunted trees.

ge—A grasslike or rushlike herb of the family Cyperaceae.

b—A short, low-branching woody perennial, usually having several main stems arising from a central point in the root system.

ulent—Refers to a characteristic related to water storage within the cells of stems and leaves, making these parts soft and thick in texture.

smontane—The other side of the mountains; for this publication, east of the main axis of the Sierra Nevada, Transverse, and Peninsular Mountain ranges.

erstory—Those plants with canopy heights at a lower level than the tallest vegetation species present.

dland—An area of land covered by trees of a characteristic form whose crowns are generally not touching.

c—Characterized by dry conditions (low rainfall).

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Paysen, Timothy E., Jeanine A. Derby, Hugh Black, Jr., Vernon C. Bleich, and John W. Mincks.

1980. **A vegetation classification system applied to southern California.** Gen Tech. Rep. PSW-45, 33 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

A classification system for use in describing vegetation has been developed and is being applied to southern California. It is based upon a hierarchical stratification of vegetation, using physiognomic and taxonomic criteria. The system categories are Formation, Subformation, Series, Association, and Phase. Formations, Subformations, and Series have been specified for current southern California plant communities. The system has application to local resource management activities and will serve as a framework for resource assessment reporting as it applies to vegetation.

Retrieval Terms: vegetation types, plant community classification, taxonomy, southern California.

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Water Repellent Soils: a state-of-the-art

Leonard F. DeBano

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LEONARD F. DEBANO was formerly a soil scientist with the Station's research unit studying the improvement of water yield in brushlands, with headquarters at Glendora, Calif. He is now in charge of research on management alternatives for southwest watersheds, Rocky Mountain Forest and Range Experiment Station, stationed at Tempe, Ariz. He earned a B.S. degree in range management and forestry at Colorado State University (1955), an M.S. degree in range management at Utah State University (1957), and a Ph.D. degree in soil science at the University of California (1966). He joined the Forest Service in 1962.

CHAPARRAL

In 1977, the Forest Service, U.S. Department of Agriculture, established a research and development program at this Station titled "Vegetation Management Alternatives for Chaparral and Related Ecosystems." This 5-year program, with headquarters at Riverside, California, is an intensive effort to develop, test, and demonstrate a wide range of operations for maintaining or increasing the productivity of chaparral and related ecosystems in southern California.

Cover: A simple field test with a water dropper shows a water repellent soil. Water repellent soils contribute to erosion after wildfires. During an intense wildfire, the temperature of the litter surface is extremely hot—as illustrated by the deformed glass bottle.

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March 1981

ater Repellent Soils:
state-of-the art

nard F. DeBano

CONTENTS

Introduction 1

Nature and Formation of Water Repellent Soils 2

Distribution of Water Repellent Soils 3

Factors Affecting Water Repellency 3

Chemistry of Water Repellency 4

Fire-Induced Water Repellency 5

Soil-Water Movement 7

Classifying Water Repellency 7

Water Repellency and Water Movement 9

Water Repellency Management 11

Beneficial Applications 11

Management Problems 13

Research Needs 15

Formation and Occurrence of Water Repellent Soils 15

Chemistry of Hydrophobic Substances 15

Soil-Water Movement 16

Vegetation Establishment and Growth 16

Runoff and Erosion 16

Research Needs in Southern California 16

Research Needs in Australia 17

Literature Cited 17

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ater repellency in soils was first described by
Schreiner and Shorey (1910), who found that some
s in California could not be wetted and thereby were
suitable for agriculture. Waxy organic substances
e responsible for the water repellency. Other studies
e early 1900's on the fairy ring phenomenon sug-
ed that water repellency could be caused by fungi.
se fairy rings created unsightly, circular shaped
s in otherwise healthy turf and lawn. Bayliss (1911)
rted on such water repellency and referred to ear-
work in 1875 by Gilbert and Laws at Rothamsted
h described the same phenomenon. Later, Shantz
Piemeisel (1917) confirmed that soil dryness was
ciated with fairy rings on grasslands in eastern
rado.

bout 30 years passed before water repellency was
rted again. Jamison (1942, 1946, 1947) found that
rd to wet'' soil was responsible for citrus decline
ase in Florida. Shortly thereafter, Van't Woudt
4, 1955, 1959) reported the effects of water repellent
tances on water movement in volcanic derived soils
ew Zealand. Also, about that time both Robinson
Page (1950) and Hedrick and Mowry (1952) discov-
that soil aggregates, which had been stabilized by
ng organics to the clay fraction, became slightly
r repellent.

eginning in 1960, interest in soil-water repellency
eased rapidly, and since then over 100 papers have
published. An early review by DeBano and others
7) summarized the state-of-the-art. This review was
wed by a more comprehensive review of soil-water
llency which was the product of an international
posium at Riverside, California, in May 1968
Bano and Letey 1969). The research on wetting
ts and water repellency, conducted by other scien-
has also been summarized (Letey and others
).

Although many have contributed to our knowledge of water repellency, several groups in particular should be acknowledged. Research scientists at the Department of Soils and Environmental Sciences at the University of California, Riverside, are recognized worldwide for their contribution to the understanding of the physics of water movement, the formation of water repellent soils, and the chemistry and application of surfactants to related soil-water problems. Several important contributions on water movement have been made by scientists at the University of Florida, Gainesville. Likewise, research on the use of water repellent substances for water harvesting has been conducted by Agricultural Research, Science and Education Administration, U.S. Department of Agriculture, at Phoenix, Arizona, which has increased our understanding of water movement in soil and the chemistry of artificial hydrophobic substances (such as silicones and plastics). Substantial insight into the chemistry of naturally occurring water repellent substances and their relationship to microorganisms resulted from research at Northern Arizona University, Flagstaff. International recognition also must be given to Dr. Roy Bond for his pioneering research on water movement, formation, and management of water repellent soils in Australia.

Forest Service scientists have also contributed importantly to water repellency research and scholarship. The most vocal was the group working under direction of the author at the San Dimas Experimental Forest in southern California. Noteworthy contributions have also been made by Dr. Richard Meeuwig, Reno, Nevada; Dr. David Scholl, Albuquerque, New Mexico; and Dr. Norbert DeByle, Logan, Utah.

The abundant documentation generated by this worldwide interest in soil-water repellency is scattered throughout the literature. Therefore, a state-of-the-art publication which summarized this information was considered germane. This report, however, should not be considered definitive; several areas in water repellency are unsolved and require major research efforts.

This report focuses on the nature and formation of water repellent soils, kinds of water repellent substances, effects of soil-water repellency on water movement, fire-induced soil-water repellency, management problems and implications of water repellency, and future research needs.

NATURE AND FORMATION OF WATER REPELLENT SOILS

Normally, dry soils readily imbibe water. A strong attraction exists between mineral soil particles and water; however, not all soils display these wettable characteristics, but repel water. For example, when water droplets are placed on the surface of an air-dry soil that is water repellent, the droplets bead up; water will not penetrate (*fig. 1*) because the mineral soil particles are coated with substances that repel water, that is, they are hydrophobic. In chemistry, hydrophobic substances have no polarity and therefore do not attract water.

This difference in wetting behavior is reflected in the comparative infiltration curves of wettable versus water repellent soils (*fig. 2*). In a wettable soil, the initial rate of water uptake is rapid because of the strong attraction between water and dry soil particles; however, as these soils wet up, the hydraulic gradient decreases and infiltration rates decrease. Conversely, a dry water repellent soil strongly resists water penetration. The initial infiltration rates are extremely slow, even nonexisten Though generally, infiltration slowly increases if wat remains in contact with the repellent soil, probably b cause water vapor advances into the soil, coalesces o isolated wettable organic and inorganic sites, an preconditions the soil. Finally, the repellent soil, onc saturated, conducts water almost as rapidly as wettab soil, although some entrapped air in the water repelle soil may slightly lower hydraulic conductivity.

Water repellency, produced by soil heating, is con mon on burned watersheds in southern California. R searchers typically notice that they leave dusty tracks i the mud as they trudge across freshly burned wate sheds after fall and winter rains. Closer examinatio reveals the soil to be unevenly wet. At or near the su face, a darkly colored soil layer can be saturated, but few inches downward is an air-dry layer of varyin thickness. Another damp or moist soil layer is prese below the air-dry layer. This layered arrangement ma be continuous over large areas or patchy and irregula The dusty tracks in the mud occur because the w upper soil layers collect on the researcher's boo exposing the underlying water repellent soil which dry. This layered arrangement was labeled the tin-roo effect by early watershed researchers.

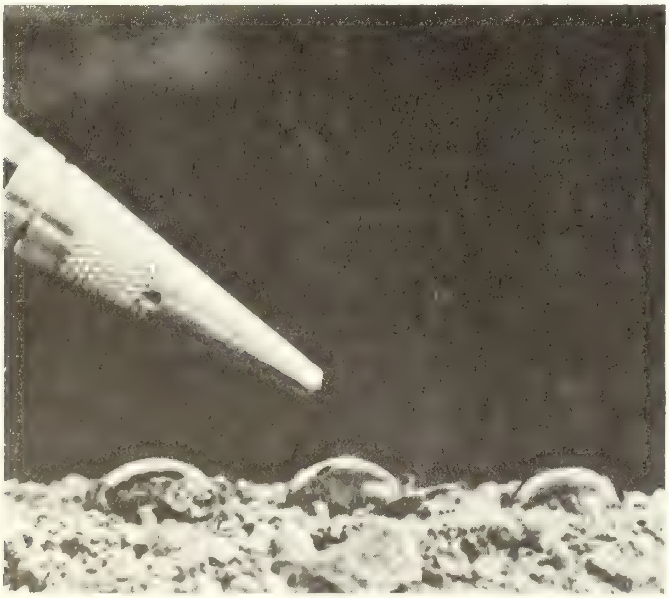

Figure 1—Droplet of water placed on the surface of a naturally occurring hydrophobic soil (DeBano and Rice 1973).

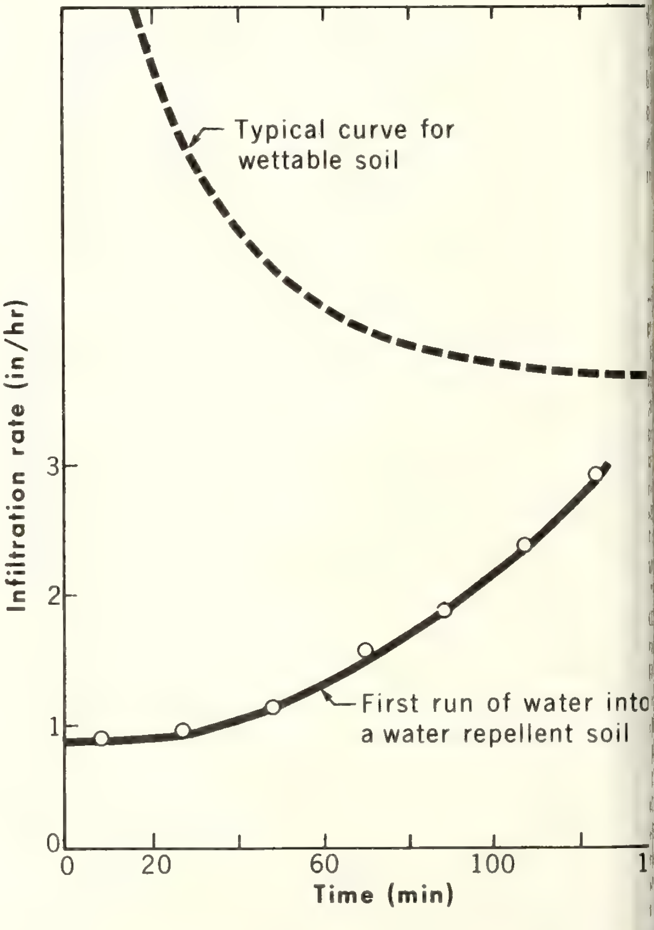

Figure 2—Infiltration rates in a water repellent soil compared to a ty infiltration curve for a wettable soil (Letey and others 1962b).

ribution of Water Repellent Soils

ter repellent soils are not isolated curiosities. They
ound throughout the world on both wildlands and
tensively cultivated lands. In the United States,
repellent soils have been reported in forests,[1]
fields,[2] grasslands,[3] agricultural lands,[4] and on
greens.[5]

tside the United States, water repellent soils have
reported in Australia,[6] Canada,[7] Egypt,[8] Holland,[9]
,[10] Japan,[11] Russia,[12] and New Zealand.[13]

e intensity and persistence of water repellency
s to vary widely, although fire-induced water repel-
generally is more severe. For example, many of
urned soils examined in southern California were
ompletely waterproofed that water drops, when
d on the surface, would evaporate before being
rbed by the soil (DeBano and Krammes 1966).
r repellency in burned soils can persist yearlong if
oils remain dry, although more transient seasonal
r repellency has been reported in some southern
ornia chaparral areas where the soils were wettable
desiccated in the summer, but extremely water
llent following autumn rains (Holzhey 1969a,b). A
s-like plant became active and created water repel-
after rains. The persistence of heat-induced water
llency depends partly on the intensity of the fire.

ater repellency persisted for thousands of years in
sols, in Alberta (Dormaar and Lutwick 1975). Many
ese soils contain charcoal and burned plant parts.
arch postulated, therefore, that the associated
n to reddish-brown horizons in these soils resulted
heat produced by burning vegetation. The extent of soil heating in the different horizons could be estimated by testing for water repellency. Those horizons containing charcoal and partly burned peat were highest in organic matter and water repellency and therefore had been subjected to temperatures ≤400° C. The brown and reddish-brown horizons were lowest in water repellency and probably had been subjected to temperatures ranging from 480 to 600° C.

Factors Affecting Water Repellency

The severity of water repellency in soils is dependent on several factors. Organic matter and soil texture are the most important factors, although fire intensity and soil water are also important parameters affecting fire-induced water repellency.

Organic Matter

Organic matter induces water repellency in soils by several means. First, irreversible drying of organic matter can induce water repellency (Hooghoudt 1950), mainly in the surface layers of peat soils which are difficult to rewet after drying (Van't Woudt 1969). Second, organic substances leached from plant litter can induce water repellency in sand and in coarse grained soils (Letey and others 1962b, Roberts and Carbon 1971, Van't Woudt 1959). Third, hydrophobic microbial by-products coating a mineral soil particle may induce a wetting resistance (Bond 1965, 1969; Bond and Harris 1964; Fehl and Lange 1965; Mathur 1970; Savage and others 1969b). Fourth, mineral particles need not be individually coated with hydrophobic materials; merely intermixing mineral soil particles with organic matter may induce severe water repellency (DeBano 1969, Meeuwig 1969). Finally, heating the coated particles or the intermixed soil can markedly increase water repellency (Cory and Morris 1969, DeBano and Krammes 1966). Heating distills hydrophobic organic substances which then condense at cooler sites (DeBano 1966, Savage 1974). If the soil is a mixture of organic matter and mineral soil, heating causes the organic matter to coat the adjacent mineral soil particles (DeBano and Krammes 1966).

The intensity and distribution of water repellency in soils seems partly related to plant species and cover density. After infiltration trials in Australia, the soil between plants remained dry, whereas the soil beneath the grass roots was wet (Bond 1964). Moreover, different types of plant covers produced different degrees of water repellency; the order of decreasing water repellency was phalaris, mallee, heath, and pine.

In contrast, other studies showed that water repellency was confined to the soil immediately beneath a plant canopy (Adams and others 1969, 1970; Gilmour 1968; Jamison 1942, 1946, 1947; Scholl 1971). In Florida, water repellency was found to extend from the trunk outward to the margin of the leaf drip (Jamison

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ee 1973; Bashir 1969; Campbell and others 1977; DeBano 1969a,
DeBano and Rice 1971, 1973; DeByle 1973; Dyrness 1976;
wig 1969, 1971a,b; Reeder 1978; Scholl 1971; Singer and Ugolini
U.S. Department of Agriculture 1971; Wells and others 1979;
nski 1971.

ams and others 1969, 1970; Bashir 1969; Cleveland 1973; De-
1969a, 1974; DeBano and others 1977; Hays 1975; Holzhey
,b; Krammes and DeBano 1965; Salih and others 1973; Teram-
73; Vogl and Schorr 1972; Wells and others 1979.

thur 1970, Richardson and Hole 1978, Schantz and Piemeisel

Bano 1969c; DeBano and Letey 1969; Jamison 1942, 1946, 1947;
iner and Storey 1910.

ller and Wilkinson 1977, Paul and Henry 1973, Waddington
Wilkinson and Miller 1978.

nd 1960, 1964, 1965, 1968, 1969; Bond and Harris 1964; Gilmour
King 1974a,b; Prescott and Piper 1932; Roberts and Carbon
1972.

rmaar and Lutwick 1975, Mathur 1970.

hay and Bakhati 1976.

oghoudt 1950.

dhikari and Chakrabarti 1976, Das and Das 1972.

akaya and others 1977a,b.

olyasev and Holodov 1958, Rybina 1967, Vladychenskiy and
a 1965, Wladitchensky 1966.

an't Woudt 1954, 1955, 1959.

1942). the Sierra Nevada, water repellency was discovered mainly in the subsoil on bare areas where the decaying roots of nearby trees and shrubs were present (Meeuwig 1971b). In Wisconsin, water repellency was weak in Mollisols under an unburned prairie but very pronounced in the mor litter layers with observable fungal mycelia (Richardson and Hole 1978). Water repellency was observed in Spodisols under red pine, hemlock, and under a mixed hardwood-softwood stand with dense ericaceous shrub understory. The repellency of mor horizons in the Spodisols seemed related to the genesis of the Spodic horizon. In Wisconsin, Reeder (1978) found that water repellency was associated with aspen but not with other forest types.

Holzhey (1969a,b) examined water repellency in southern California, across a transect of several vegetation types. In the chaparral plant communities, water repellency was least in the coastal sage scrub where a scant litter layer was present and greatest in the woodland chaparral dominated by *Arctostaphylos* sp., *Ceanothus* sp., *Quercus dumosa*, and *Rhamnus crocea*. In pinyon-juniper woodlands, water repellency was least severe under *Artemisia tridentata* and most severe under stands of *Pseudotsuga macrocarpa*. No attempt was made to correlate plant species to type of microorganism present under each vegetation type. Teramura (1973) observed that water repellency in chaparral stands was related to stand age but not species composition.

Soil Texture

Soil texture affects the degree of water repellency when organic matter is added to, or allowed to decompose in, soils. Normally, organic matter added to soils is considered desirable; soil structure improves, which correspondingly enhances aeration and water movement. Contrarily, however, organic matter can induce water repellency in coarse textured soils, which severely restricts water movement (Meeuwig 1969, 1971a,b). In Australia, water repellency in sandy soils produces severe management problems (Bond 1965, King 1974b). Conversely, in finely textured soils, organic matter forms water-stable aggregates which improve aggregate stability and water and air movement (Hedrick and Mowry 1952).

Chemistry of Water Repellency

The characterization and identification of naturally occurring water repellent substances has been studied with varying degrees of complexity. Although the substances responsible for producing water repellency are definitely organic, the amount of organic carbon and the degree of water repellency are not directly related (DeBano and others 1976). The ease of extracting hydrophobic substances has been used to characterize water repellency. Simple water solutions containing substances extracted from chaparral plants can mak sands water repellent (Letey and others 1962b). Alka solutions such as ammonium hydroxide also remov substances from plant litter that can induce water repe lency in sand or coarse-textured soil (Letey and othe 1962a).

The solubility of hydrophobic coatings in various o ganic solvents also has been used to characterize wat repellency. Wander (1949) showed that such coating from Florida soils were soluble in methanol; he believe they were calcium and magnesium soaps. Van't Wouc (1959) found that the particle coatings causing wate repellency in Taupe volcanic soils in New Zealand wer so strongly adsorbed that they could not be remove with 2 hours of refluxing with ether in a Soxhlet ap paratus. In another study (Montana Agric. Exp. Statio 1963), substantial amounts of organic materials wer removed by extraction with hot alcohol in a Soxhle The tenacity of adsorption was also demonstrated i Hawaiian soils where neither ethyl nor petroleum ethe could extract the hydrophobic substances (Uehar 1962).

The hydrophobic organic skins on sandy soils c southwestern Australia were resistant to removal b cold water, concentrated acid, diethyl ether, ethano benzene, chloroform, and acetone (Roberts and Carbo 1972). Prolonged treatment with hot diethyl ethe ethanol, and benzene removed part of the coating Treatment with dilute solutions of alkali removed th skin as suspended particles. The organic hydrophobi substances produced by fire cannot be extracted fro naturally occurring soils with mixtures of eithe benzene-acetone (Savage and others 1972) o benzene-methanol (Savage 1974), although thes substances are extractable when collected on angula quartz sand.

The chemical identification of substances responsib for water repellency is complex; a host of organi substances of unknown composition seems involve An early study (Prescott and Piper 1932) suggested th essential oils from xerophytic vegetation produce water repellency. Work on southern California chapa ral showed that both water soluble and highly volati secondary products contribute to water repellenc (Teramura 1973). Wander (1949) concluded that calciu and magnesium salts of fatty acids were responsible fo water repellency. Attempts to characterize th substances as crude fat have been futile (Van't Wouc 1959, Uehara 1962).

Much has been done to chemically characterize thes substances via humic acids (Roberts and Carbon 1972 Savage and others 1969a,b; Singer and Ugolini 1976 Wladitchensky 1966; Adhikari and Chakrabarti 1976) however, not all humic acids can cause water repel lency. Of the several humic acids tested, only one whic was recovered from a culture solution of *Stachybotry atra* has produced water repellency in sand and so (Savage and others 1969a). The analysis of soils col

d from beneath a hemlock-fir forest in Washington
ed that water repellency was highly correlated
the humic-fulvic acid ratio (Singer and Ugolini
). Chen and Schnitzer (1978) found that a fulvic acid
iency in the soil solution would produce water
lency, and conversely, an ample supply of fulvic
increased soil wettability. The organic coatings on
r repellent sand grains from localized dry spots on
greens produced an infrared spectrum similar to
c acid (Miller and Wilkinson 1977). A comprehen-
elemental and spectroscopic analysis of the organic
tances contributing to fire-induced water repellency
ils revealed that the organic substances were basic-
aliphatic hydrocarbons (Savage 1974).

e extractive resistance of hydrophobic soil coat-
suggests that they are strongly adsorbed; however,
ature of the bonding is not fully understood. Van't
dt (1959) concluded that the hydrophobic coatings
strongly adsorbed on the mineral surfaces by
plex radicals. Cory and Morris (1969) suggested
extensive polymerization occurs, possibly by hy-
en bonding. A mineralogical study by Uehara and
ng (1963) showed that silanol groups on the clay
ces of minerals were partly responsible for water
llency. The hydrophobic substances produced dur-
urning exhibit high polarity which is believed to be
onsible for their becoming tightly fixed in the soil
age 1974).

Fire-Induced Water Repellency

Water repellency caused by wildfires in southern California chaparral has received the most attention (DeBano and others 1967, DeBano 1979), although repellency has been reported after wildfires in forests (Campbell and others 1977, Dyrness 1976) and in grasslands (Richardson and Hole 1978). In southern California, organic matter accumulates in the litter layer during the intervals between fires. During these intervals, the upper soil layers become water repellent due to the intermixing of partially decomposed organic matter and mineral soil (*fig. 3A*) and due to the leachate from brush and decomposing plant parts which become deposited in the upper soil profile. Fungal growth also can produce water repellency in this part of the soil.

Heating during a fire markedly changes and intensifies water repellency. When a fire occurs, the litter and upper soil layers are exposed to very intense heating, particularly during an intense burn (*fig. 3B*). Temperatures in the plant canopy may soar to 1093° C (Countryman 1964). Temperatures at the soil surface are less but may reach 843° C (Dunn and DeBano 1977). Within the upper soil layers, the temperature drops rapidly because dry soil is a poor conductor of heat. At 5 cm below the surface, the temperature is not likely to exceed 150° C (DeBano and others 1977). Incipient water repellency at the different depths may be intensified in

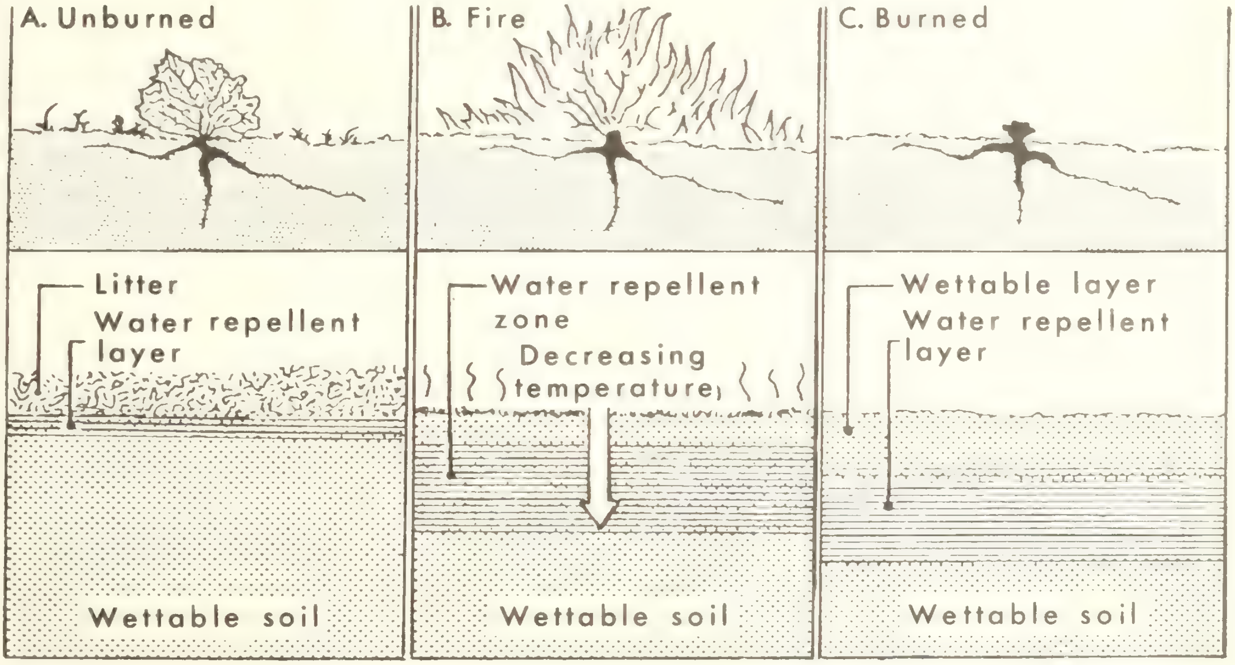


Figure 3—Soil-water repellency as altered by fire: *(A)* before fire, hydrophobic substances accumulate in the litter layer and mineral soil immediately beneath; *(B)* fire burns the vegetation and litter layer, causing hydrophobic substances to move downward along temperature gradients; *(C)* after fire, a water repellent layer is present below and parallel to the soil surface on the burned area (DeBano 1969).

place by heating because the organic particles are heated to such an extent that they coat and are chemically bonded to the nearby mineral particles.

More important than the absolute temperature at any depth are the temperature gradients developing across the upper few centimeters of soil. Substances which are vaporized at the soil surface can be moved downward into the underlying soil by these gradients. The vaporized substances then condense on mineral soil particles and are rendered extremely water repellent (DeBano 1966). After a fire has swept through an area, a water repellent layer of varying thickness remains (*fig. 3C*). This layered arrangement allows rainfall to infiltrate only to a limited depth before the wetting front reaches the water repellent layer.

Experimental Confirmation of Theory

Letey and his co-workers (1962a) were the first investigators to show that water repellency in chaparral soils was caused by organic substances. Later, DeBano and Krammes (1966) found that water repellency could be changed radically by heating. Samples of slightly water repellent topsoil containing some organic matter were placed in a muffle furnace and heated; the water repellency was either intensified or destroyed. For example, heating for 20 minutes to 260° C produced an extremely water repellent condition. In contrast, heating to 371° C for only 20 minutes started to reduce water repellency. That substances must move along temperature gradients became apparent after field observations revealed water repellency at deeper depths where soil heating was not sufficient to intensify water repellency. The translocation of hydrophobic substances was confirmed by experiments in which heat was applied to the surface much as occurs during a natural fire (DeBano 1966, DeBano and others 1970). These experiments were designed to measure the hydrophobic substances distilled downward into formerly wettable sand, thereby demonstrating that hydrophobic substances are moved along temperature gradients.

Chemistry and Thermal Stability

Once established that organic substances moved along temperature gradients, experiments were made on the chemistry of these substances, their thermal stability, and the soil physical factors affecting them. Chemical analysis was made of the compounds causing heat-induced water repellency since chemical identification was thought necessary before remedial treatments could be intelligently prescribed. Wetting agents had been used with varying degrees of success, but their specific interaction with hydrophobic substances was obscure (Osborn and others 1964, Pelishek and others 1962). In one such experiment, substances emanating from a heated water repellent soil were captured, fractionated by adsorption chromatography, and subjected to elemental and spectroscopic analyses (Savage and others 1972). These analyses showed that the greatest amount of organic substances was released above 300 C and that the amount released increased with the risin oxygen content (up to 20 percent) of the gas passin through the combustion chamber.

Chemical analyses of these fractions showed that th substances causing water repellency were aliphatic hydrocarbons formed from partly decomposed plant materials in the soil. When these substances were placed o wettable sand, extreme water repellency was produce only after heating the treated sand. The suggestion wa that additional heating after condensation was necessary to fix the hydrophobic substance and produce extreme water repellency. Savage (1974) later confirme these results. He used sand columns under burnin manzanita litter to show that the degree of water repellency was less when burning litter was immediately removed, before the heat had penetrated into the sand than when the burning litter was left in place and allowed to heat the underlying sand. He concluded tha the movement of organic substances from litter occurred mainly when the fire was actively burning. Afte burning, heat moving downward through the underlyin sand fixed some of the more polar hydrophobi substances and revolatilized the less polar ones, thereb broadening the water repellent layer. The temperatur required to fix and revolatilize the substances wa greater than 250° C. DeBano and others (1976) analyze polarity, extractability, oxygen content, and relate water repellency. Their tests showed that substance with greater polarity and higher oxygen content produced less hydrophobicity when heated to 250° C The less polar substances moved further downward in the soil, producing a higher degree of water repellency.

These studies provide general guidelines on the thermal stability of substances responsible for water repellency. Most studies (Savage 1974, Scholl 1975 DeBano and others 1976, Dormaar and Lutwick 1975 generally agree that the substances responsible fo water repellency are destroyed when heated over 288 C. Very intense water repellency is formed when soil containing hydrophobic substances are heated betwee 176 and 204° C. Temperatures of at least 250° C are necessary to fix the translocated substances.

Fire Intensity and Soil Water

In burned soils, the severity of water repellency no only depends on soil texture, but also appears related to both intensity of fire and soil-water content (DeBan and others 1976). Light burns in chaparral over dry soil produce the thickest and most highly water repellent condition. The least severe water repellency is produced when a light-intensity-chaparral fire burns over a wet soil. To this end, Dyrness (1976) found that the wettability of soils in stands of lodgepole pine burned lightly by a wildfire recovered more rapidly than soils in intensely burned areas. By the sixth year after the fire, the wettability of both lightly and intensely burned soils was approaching that of the unburned soil.

IL-WATER MOVEMENT

ater movement can be severely limited by hydro- ic organic materials which are either intermixed the soil or coat the mineral soil particles. The infil- on curves for wettable and water repellent soils ented earlier reflect this effect (*fig. 2*). The practical ications of water relations in these hard-to-wet soils h as the effects on plants, runoff, and erosion) has o numerous studies on water movement.

ne effect of hydrophobic substances on water ement in soils provides a basis for characterizing r repellency. Several methods of varying sophisti- on used to characterize water repellency include erdrop penetration time (WDPT), equilibrium d-solid contact angles, solid-air surface tension in- s, and the characterization of dynamic wetting an- during infiltration. The in-depth principles of soil sics used to develop some of these methods are con- ed in two excellent reviews describing the basic ry—Letey and others (1975) and DeBano (1975).

ssifying Water Repellency

etey and his co-workers (1975) point out that soils usually classified as either wettable or water repel- , implying a sharp dichotomy; however, water repel- y is a relative soil property and may vary widely in nsity. Any practical method of classification must be to quantify or, at most, index the degree of water llency with time. Most of the methods described are quantitative and treat water repellency as a tive soil property. The simpler techniques, such as erdrop penetration time, are described in sufficient il to allow the reader to use them. The more funda- ital principles provide a basis for describing the ef- of hydrophobic substances on water movement dur- infiltration and evaporation.

erdrop Penetration Time

ne of the simplest and most common methods of sifying water repellency is to determine the time a erdrop takes to be absorbed by the soil sample. A erdrop is placed on the sample surface (*fig. 1*) and length of time to be absorbed is timed. Theoreti- y, if the wetting angle is greater than 90 degrees, the er droplet will remain on the surface until it evapo- s; if the angle is less than 90 degrees, pore capillary es will pull the water into the soil. In fact, the dis- tion between a wettable (wetting angle less than 90 rees) and a water repellent soil (wetting angle greater n 90 degrees) is not that simple because water repel- y seems to be time dependent in many cases. That the wetting angle of the water droplet will change over time and the water droplet, although not immediately absorbed, will penetrate the sample at a later time. Some water repellent soils have wettable soil particles and organic debris that will move onto the water droplet, causing it to penetrate into the soil. Such complications arising from the time dependency have led to the establishment of arbitrary time limits when classifying soils as wettable or water repellent. Researchers found that water droplets remaining longer than 5 seconds usually resisted penetration for several minutes and thus the soil could be classified as water repellent (Krammes and DeBano 1965).

Sometimes measurement of waterdrop penetration longer than 5 seconds is desirable for obtaining information on the persistency of water repellency. Another technique was therefore developed which uses the critical surface tension of the infiltrating solution (Watson and Letey 1970, Watson and others 1971). Critical surface tension is defined as the liquid surface tension which permits just wetting of a soil (that is a 90-degree contact angle). The critical surface tension can be easily and quickly determined in the field or laboratory with a series of aqueous ethanol solutions. Pure ethanol is diluted with distilled water into separate solutions containing different percentages of ethanol on a volume basis. (The corresponding surface tension of these solutions can be obtained from a physics and chemistry handbook.) A drop of each solution is placed on the soil surface and the time of penetration determined. If the drop penetrates instantaneously (less than 5 seconds), the surface tension of that solution is considered to be at the critical surface tension. A water repellency index is then obtained by dividing the critical surface tension (dynes/cm) into the time (up to 600 seconds) required for a water droplet to be absorbed by the soil (Letey and others 1975). For practical purposes, waterdrop penetration times are not measured beyond 10 minutes. A repellency index value greater than 10 indicates an extremely water repellent soil; 1 to 10 is moderately water repellent; 0.1 to 1 is slightly water repellent; and less than 0.1 is wettable (Letey and others 1975). When this technique was compared with other, more complicated, techniques involving liquid-solid contact angles during capillary rise, the results agreed closely (Letey and others 1975).

Equilibrium Liquid-Solid Contact Angles

Porous media such as soils are often viewed as simple or multiple capillary systems. The pores are considered analogous to capillary tubes (Emerson and Bond 1963, Letey and others 1962a, Vladychenskiy and Rybina 1965, Yuan and Hammond 1968). Water movement can thus be described by capillary rise models which are based on the attraction between water molecules and the walls of the capillary tube. In soils, capillary rise occurs because of an attraction between the water molecules and soil particle surfaces.

When water moves up a capillary tube, the water meniscus forms a definite and measurable angle with the glass wall of the tube. The capillary rise equation relates the height of rise of the water and the contact angle, as follows:

$$h = \frac{2\gamma}{r\rho g}\cos\theta$$

in which

h = height of rise
γ = surface tension
r = radius of capillary
ρ = density of the liquid
g = gravitational term
θ = angle between the water meniscus and the wall (wetting angle).

If the capillary wall is made of clean glass, the wetting angle, θ, should be zero. If the angle is zero, the height of rise is directly related to the surface tension and inversely related to the tube radius (that is, the smaller the radius of the tube, the higher the capillary rise). Coating the capillary tubes with hydrophobic substances reduces the attraction between the water and the glass walls. The water therefore will not rise as high as in a clean tube.

The concept of a wetting angle provides a useful technique for quantifying soil wettability (Letey and others 1962a). Pure ethanol wets all solids (even hydrophobic ones) at a zero contact angle. Various liquids, including n-heptane (Bahrani and others 1973, Kijne 1967, Miyamoto and Letey 1971), have been used experimentally, but not as widely as ethanol. Therefore, equation (1) can describe capillary rise of water and ethanol. In both cases, two parameters (θ and r) are not known or readily measured. The surface tension and density of water and ethanol can be measured or referenced in a handbook. The known gravitational constant is the same for both liquids. The height of rise for both water and ethanol can be measured easily in the laboratory. Finally, if the wetting angle of ethanol is assumed to equal zero (thus, $\cos\theta = 1$) and the capillary radius remains constant, then equation (2) can calculate the apparent liquid-solid contact angle:

$$\cos\theta_w = 0.369\frac{hw}{he}$$

in which

θ_w = apparent liquid-solid contact angle
hw = height of rise of water (cm)
he = height of rise of ethanol (cm)

The factor of 0.369 was derived from known values of density and surface tension of water and ethanol (at 20° C).

Laboratory tests determine the apparent liquid-solid contact angle (θ_w) by packing two similar glass tubes with the test soil. Though the size can vary, glass tubes averaging about 4.8 cm in diameter by 53 cm long have been used (Letey and others 1962a). Smaller diameter tubes may complicate the results because of edge and boundary effects. The bottom of the glass tubes are covered with cheesecloth or fine mesh screen which retains the soil at the bottom of the tube but allows the water or ethanol to move up. When filling the two tubes with soil, care should be taken to pack them to identical density. Finally, the end of one column is immersed in water, the other in pure ethanol. The height of capillary rise of both solutions can be readily observed through the walls of the glass tubing. After 24 hours, the height of capillary rise of the two solutions is measured and used in equation (2) to calculate the apparent liquid-solid contact angle. The larger the angle, the greater the water repellency, with angles up to 90 degrees obtainable.

Energetics of the Soil-Water-Air Interface

The theoretical basis underlying the above methods, particularly the apparent liquid-solid contact angle, has caused reexamination of the theory of wetting in water repellent soils. Several inadequacies arise when characterizing water repellency by liquid-solid contact angles (Bahrani and others 1970). A liquid-solid contact angle (θ_w) in a porous medium with the complex pore geometry of soil is difficult to visualize. Electron microscopic examination of wetting on the surface of hydrophobic sand grains illustrates the traditional liquid-solid contact angle model based on capillary rise, but does not represent a real soil (Bond and Hammond 1970). Such examinations reveal that the effective contact angle really is the sum of a finite contact angle measured between the solid and the liquid-air interface and the angle of divergence of the soil pore. Although some media are considered completely water repellent, some attraction for the water usually exists and water enters slowly. This action is probably related to the persistency of waterdrops. Extremely water repellent materials have been shown to adsorb some water slowly by vapor diffusion (Hanks 1958, DeBano 1969b, Miyamoto and others 1972). Also, liquid-solid contact angles do not explain the physical nature of water repellency, particularly in terms of the energetics of the soil-water-air interface.

Two methods for evaluating water repellency have been developed which are not subject to the above limitations: one determines a wetting coefficient (Bahrani and others 1970), the other determines the solid-air surface tension of the medium (Miyamoto and Letey 1971). Two wetting coefficients based on Young's "Work of Adhesion" and Moillets' "Work of Droplet Adhesion" are described and discussed in detail by Bahrani and others (1970). The technique for determining solid-air surface tension of porous media has a different theoretical basis and is derived from Fowkes' dispersion theory and the capillary rise equation (Miyamoto and Letey 1971).

acterizing Water Repellency During Infiltration

ils with wetting angles less than 90 degrees but er than 0 should transmit water, although infiltra- is slower than if completely wettable. The intensity persistence of water repellency determines the flow Several techniques have been developed to acterize wettability during infiltration. A couple niques employ saturated flow equations to derive d-solid contact angles from the measurements n on the advancing wetting front (Letey and others a, Emerson and Bond 1963). Another approach es unsaturated flow rates, characterized within the ework of a diffusivity analysis, to evaluate the ef- of water repellency on water movement at different water contents (DeBano 1969b, 1971).

e first attempt to characterize the liquid-solid con- angle during infiltration was based on Poiseuille's tion (Letey and others 1962a). Both water and nol were infiltrated into the test soil. The relative derived from those tests served as the basis to late liquid-solid contact angles in much the same od as for capillary rise. The Darcy flow equation applied in another infiltration technique to calculate advancing contact angle for water repellent sands erson and Bond 1963). Instead of using ethanol to lish a zero contact angle, part of the sand was ig- l to destroy the organic matter responsible for water llency. The ignited sand was assumed to be wet at contact angle by water.

nsaturated flow measurements have also served to ulate liquid-solid contact angles at different soil- r contents in wettable and water repellent soil (De- 1969b). This approach employed the concept of nsic soil-water diffusivities (Mustafa and others). The diffusivities were determined from labora- measurements during the horizontal infiltration of r or ethanol into wettable and water repellent soils served to calculate liquid-solid contact angles at different volumetric water contents. The results showed that as the water content of a wettable soil increased, the liquid-solid contact angle increased as well. In a water repellent soil, however, the wetting angle decreased with increasing water content because some of the hydrophobic sites wetted up after exposure to water. The results presented here agree well with our understanding of water movement in wettable and water repellent soils.

Water Repellency and Water Movement

Usually, dry soil readily absorbs water because of a strong attraction between the mineral particles and water. In terms of the liquid-solid contact angles, highly wettable soil behaves as though these angles are zero. The affinity of soils for water can be reduced by coating the particles with hydrophobic substances, thereby increasing the liquid-solid contact angle (Wladitchensky 1966, Letey and others 1962a,b, Rybina 1967). As an important water moving force, changing capillarity also affects infiltration and evaporation.

Infiltration

Wetting Patterns—The infiltration curve given for a water repellent soil in *figure 2* reflects increasing wettability over time once the soil is placed in contact with water. Infiltration increases with time because the substances responsible for water repellency are slightly water soluble and slowly dissolve, thereby increasing wettability. Also, the hydrophobic substances on the particle surface may not be continuous and water may move into the soil by vapor diffusion where it is adsorbed on wettable sites which improves wettability of the entire soil.

Under field conditions the water repellent layer is usually not continuous, so irregular wetting patterns are

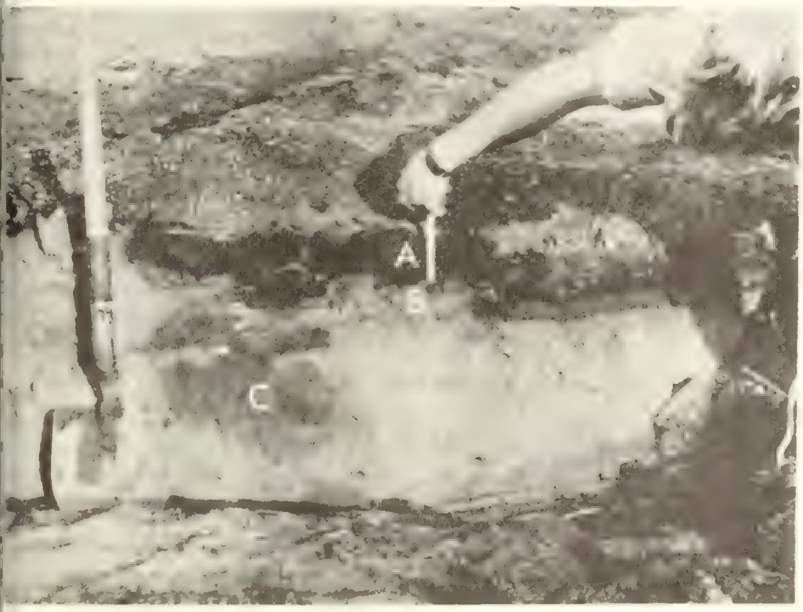


Figure 4—Exposed soil profile showing the tin roof effect. The moist surface layer *(A)* is underlaid by dry water repellent soil *(B)*, with some evidence of moisture penetration through the water repellent layer *(C)* (DeBano 1969).

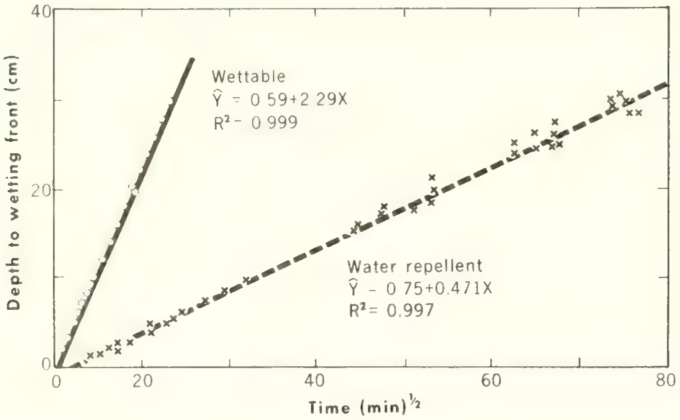


Figure 5—Relationship between time and distance to the wetting front during a horizontal infiltration trial into wettable and water repellent soil (DeBano 1971).

common (*fig. 4*). Irregular wetting has been reported under citrus trees in Florida (Jamison 1942). In Australia, the severest water repellency has been observed in bare areas between clumps of grass; following rainstorms, wetted areas were found primarily beneath the crown of the grasses, but not in the spaces between plants (Bond 1964). Large water repellent areas in grasslands, historically described as fairy ring phenomena caused by microbe-induced water repellency, also produce irregular wetting (Shantz and Piemeisel 1917). Meeuwig (1971a) found irregular wetting patterns developing during infiltrometer trials on unburned forest and brush areas. In desert communities, soil beneath the shrub canopy was discovered to be water repellent, whereas the area outside the canopy was completely wettable (Adams and others 1969).

Laboratory Studies—Infiltration into wettable and water repellent soils has been the subject of intense laboratory testing. These studies showed that the wetting front during infiltration in wettable soils not only develops faster but has a different shape than those developing in water repellent soils (DeBano 1971). In one case, infiltration was 25 times faster in wettable soils than in water repellent soil (*fig. 5*). The linear relationship between distance to the wetting front and the square root of time commonly found in wettable soils was less well defined (although the correlation was high) in the water repellent soil because of irregular wetting. The irregular and incomplete wetting was also reflected in the soil-water distribution pattern (*fig. 6*). For example, the water content decreased as much as 20 to 25 percent between the water source and the wetting front which was very diffuse and poorly defined. By comparison, the water content of the wettable soil decreased only 10 percent over the same distance. A subsequent diffusivity analysis of the infiltration data indicated that hydrophobic substances had a greater effect on water movement in unsaturated soil when the soil was dry; the effect diminished as water content increased. The slow water uptake at the beginning of infiltration is importar from the standpoint of erosion and runoff, although th effect on cumulative infiltration over longer periods c time may not be large.

Layered Soil—A water repellent layer is common i soils under field conditions. As in southern Californi this layer may be formed after fire (*fig. 3C*). These wat repellent layers affect infiltration in much the sam manner as a coarse textured layer in the soil profil When this water repellent layer is beneath a wettab surface layer, the wetting front moves rapidly throug the wettable layer until it reaches the water repelle layer (*fig. 7*). The infiltration rate then drops immed ately to that of the water repellent layer, where it r mains even after the wetting front has again moved int the wettable soil beneath the water repellent layer (D Bano 1969b). The depth to the water repellent layer als affects infiltration rates. A water repellent layer near th surface will more effectively restrict infiltration than deeper layer (Mansell 1969).

Evaporation

Hydrophobic substances reduce evaporation becaus the capillary forces necessary to move water to the so surface are lessened. For example, sands made wate repellent with a chaparral litter extract lost 45 percent c the water in contrast to a wettable sand which lost 6 percent of the water during the same period (Letey an others 1962b). Another laboratory experiment (DeBan 1969b) showed that the water loss from a water repellen sandy loam soil was less than from a wettable soil o similar texture. Examining the soil-water distributio patterns after evaporation revealed that water wa withdrawn from all depths in the columns filled wit wettable soil. In contrast, columns containing onl water repellent soil lost water primarily from the uppe

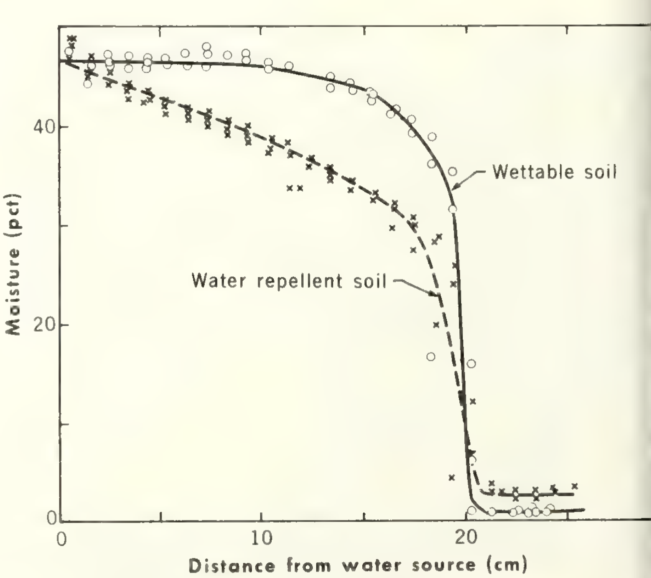
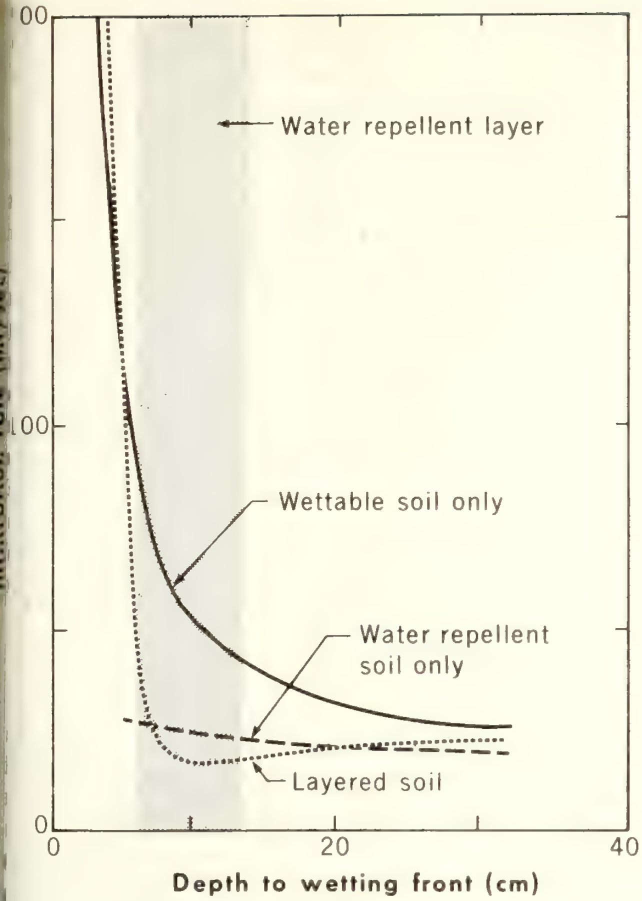


Figure 6—Soil-water distributions developed during infiltration into co umns packed with wettable and water repellent soils (DeBano 1971).



ıre 7—Infiltration rate when the wetting front approached different hs in soil columns packed with only wettable soil, water repellent soil, yered soils (DeBano 1969c).

ers because water in the deeper layers was unable to ch the surface by capillary flow.

)ther investigators (Kolyasev and Holodov 1958) reted that water repellent samples lost water faster n wettable samples; however, evaporation occurred hin layers of hydrophobic soil, and capillarity apparly did not play a major role in moving water through soil mass to the evaporating surface. Instead, the raction between the particles and water directly conlled the evaporation rate. Therefore, water repelcy appears to decrease evaporation where water st move to the evaporating surface by capillary flow. r this reason, many of the hydrophobic mulch matels added to the soil surface are effective in conserving l water (Hergenhan 1972, Hillel and Berliner 1974, mon 1956, Kimball 1973).

er Soil-Water Characteristics

oil-Water Potentials—Water repellent substances ect water held at different soil-water potentials. ter repellent sands hold less water at 0 to −0.05 bar -water potential during sorption and desorption than ilar wettable sands (Letey and others 1962b). The ne is true for soils having water potentials between 0 and −1/2 bar. At soil-water potentials between −1/2 and −15 bars, however, water repellent soils hold more than wettable soils (DeBano 1975). At soil-water potentials between 0 and −1/2 bar, the weaker attraction between the soil and water (large liquid-solid contact angle) permits more water to be drawn out of the water repellent soil. In contrast, at potentials more negative than −1/2 bar, the hydrophobic substances hinder the movement of water out of water repellent soil and more water is retained in water repellent soil than in wettable soil.

Water Transfer Mechanisms—Some studies on water movement suggest that different water transfer mechanisms are operating in wettable and water repellent soils. Water moves in soil by liquid or vapor flow. In water repellent soils, liquid flow across particle surfaces coated with hydrophobic substances probably is severely hindered. Differences in capillary rise suggest weaker liquid particle attraction and less liquid flow. When liquid flow is restricted, vapor movement undoubtedly begins to play a major role in water movement because most studies suggest vapor flow is perhaps not affected by hydrophobic coatings (Brandt 1969a, Hanks 1958, Hemwall and Bozer 1964, Miyamoto and others 1972).

WATER REPELLENCY MANAGEMENT

The effects of water repellent soils may be adverse or benign, depending on the efficiency of repellency management programs. In some cases, water repellency is induced by naturally occurring organic substances or artificial materials in order to conserve water, reduce nutrient loss, or improve soil structure. But water repellency may be undesirable and require some special management action to counteract its deleterious effects. An acute management problem in southern California is the high runoff and erosion rates caused, in part, by heat-induced water repellency.

Beneficial Applications

Water Conservation

The relationship between water repellency and soil-water movement has been successfully utilized to conserve water. Water loss by evaporation from the soil surface can be reduced by several methods, thereby making it available for plant growth or other applications such as ground water recharge. Sealing the soil surface with water repellent materials also allows for water harvesting—a method of efficiently harvesting precipitation.

Evaporation Control—Water can be conserved and stored in the soil if it is not permitted to move to the soil surface where it can be lost by evaporation. The amount of water moving to the soil surface can be reduced by decreasing the surface tension of the soil water, decreasing the wettability of the pore walls, and increasing the size of the soil pores (equation [1]). The surface tension of soil water can be decreased by applying surfactants (Lemon 1956). The wettability of the soil pore walls can be decreased by coating the soil particles with hydrophobic substances (DeBano and others 1967, DeBano 1975). The effective pore size of the surface layers can be increased by mulching (Kimball 1973) or by aggregating the small particles with chemicals such as soil conditioners (Gabriels and others 1973, Hillel and Berliner 1974, Rawitz and Hazan 1978).

Water Harvesting—The technique of water harvesting has been successful in developing local water supplies in remote areas for livestock, wildlife, runoff farming, and domestic use (Frasier 1975, Myers 1964). The runoff water produced by waterproofing the soil surface can be collected and stored or used on site, depending on the local need.

Although water harvesting can be accomplished in several ways, one effective method treats the soil surface with materials which prevent water from soaking into the soil (Cooley and others 1975). Several types of materials to waterproof the soil surface are asphalts (Frasier and Myers 1972), waxes (Fink 1977, Fink and others 1973, Hillel 1967), silicones (Myers and Frasier 1969), plastics (Myers 1964), and oils (Fink and Mitchell 1975, Hillel 1967). Both laboratory (Fink 1974, 1976) and field (Fink and Frasier 1977) evaluations have been made of most currently available materials. These tests show that silicone and wax-treated water repellent catchments weather quite differently (Fink and Frasier 1977). The silicone treatment showed a uniform deterioration throughout the treated zone, whereas the wax treatment showed a progressive deterioration beginning at the top of the treated profile. A laboratory test (Fink 1976) showed that when two repellents (petroleum resin and paraffin wax) were combined, the soil was rendered generally more resistant to total weathering effects than either repellent alone.

Nutrient Leaching

The leaching of soluble fertilizers out of the root zone of vegetable beds is an important management problem in parts of Florida (Snyder and Ozaki 1971). The leaching losses are greatest in coarse textured soils which have a low exchange capacity because clay and organic matter are lacking. This problem was successfully solved by applying water repellent mulches to reduce leaching and fertilizer loss (Snyder and Ozaki 1971, Snyder and others 1974). Nitrogen and potassium leaching from a fertilizer band in sandy soil (on the flat surface of raised vegetable beds) was reduced by a 1 percent siliconate spray in quantities sufficient to penetrate a 20-cm wide area to a depth of about 3 cm.

Soil Improvement

Both naturally occurring and artificial water repellent substances have been utilized to improve the physical, chemical, and electrical properties of soils. The properties are improved because these substances improve either aggregation (soil structure) or waterproofing, thereby preventing water from entering the soil and changing its physical properties.

Aggregation—Soil aggregation, which is important for soil structure, is highly dependent on soil wettability. Aggregation occurs when individual soil particles are bound together by naturally occurring or artificial organic compounds (Harris and others 1966). Not only do these organic compounds hold the soil particles together, but the more effective materials stabilize the aggregates by making them water repellent (Hartmann and others 1976, Gabriels and others 1973). Water repellency affects flow in saturated soils by increasing the stability of aggregates, thereby maintaining soil structure (Brandt 1969a). Treating these stable aggregates with a wetting agent causes them to wet up and become less stable (Mustafa and Letey 1969). The stability of aggregates to slaking in water (Yoder 1936) has been recognized as a desirable soil property when evaluating erodibility of different soils (Anderson 1951).

Naturally occurring organic matter increases aggregation and soil stability by reducing swelling and the destructive forces of entrapped air, decreasing wettability, and strengthening the aggregates (Robinson and Page 1950). The mechanism responsible for aggregation in a Krasnozem soil were found to vary among different particle size classes (Coughlan and others 1973). Basic soil properties were important for aggregating the<0.5-mm particles, whereas the hydrophobic properties of organic matter had the greatest effect on aggregate stability in the 0.5- to 5.0-mm size class of aggregates. Above 5.0 mm, binding by plant roots was the most important aggregate mechanism. Organic matter, when modified by microbial growth, can also increase the water stability of soil aggregates (Fehl and Lange 1965).

Organic matter in soils has been customarily considered beneficial to soil structure and related soil properties that affect water movement; however, this concept must be modified in view of our present understanding of water repellency. Previously, organic matter in any amount was assumed to be beneficial to any soil, since organic matter aggregated soil particles and produced a more porous soil structure that allowed water to infiltrate and move more readily through the soil. The current view is that organic matter is beneficial to fine-textured soils because individual mineral particles are aggregated, producing large pores which permit water to move more readily; when not aggregated, the fine soil particles provide small pores which restrict water movement. In a coarse-textured soil, larger particles become packed as single grains so that large pores are produced. These pores are sufficiently large to permit rapid water movement. But when organic hyhobic substances are added, they increase aggrega- only slightly; moreover, these substances coat in- dual soil particles and restrict, or in some cases pletely impede, water movement (Meeuwig 1969). impermeability of coarse textured soils has been rted as a severe management problem in sandy tralian soils (Bond 1968). Apparently, therefore, esirable features of water repellency in coarse-tex- d soils must be balanced against the advantages of er-stable aggregates produced by organic matter in -textured soils.

he desirable features of aggregation have led to ex- ive research of synthetic organic materials as soil egating agents. The organic materials most widely lied in aggregation are usually large molecular or- c compounds whose structure ranges from well- ned synthetic polymers to complex mixtures of rly defined and understood products, which are uently waste products (Schamp and others 1975). se substances are generally referred to as soil con- oners. The wide variety of soil conditioners, their orption and adhesion properties, and their effect on er movement are discussed in a comprehensive re- v by Stewart and others (1975). The usefulness and irability of these soil conditioners depend, however, heir ability to produce water-stable aggregates.

aterproofing and Structural Stability—Some en- ering applications require that a soil be made essen- y waterproof. Although the treatments per se may improve the physical properties—such as soil ngth—they do allow the dry strength of the treated s to be retained when exposed to water (Brandt 9b, Hemwall 1963, Hemwall and Bozer 1964, Hem- l and others 1962, Kolyasev and Holodov 1958). terproofing has been successful in maintaining the ility of highways exposed to freezing and thawing. vater is permitted to penetrate under the pavement ing freezing, a saturated nonfrozen layer is produced r a frozen layer during thaw. When traffic loads are lied to this system, the release of hydrostatic pres- e tends to be upward, resulting in pavement blow- s. Waterproofing the layer immediately below the ement prevents moisture accumulation and sub- uent problems. Waterproofing chemicals for this pose include substituted phenols, long-chain amines, orosilanes, and benoxazines (Bozer and others 9).

nagement Problems

-Induced Water Repellency

ny mineral soil containing more than a couple per- t of organic matter is likely to become water repel- t to some degree when heated. The severity and dis- ution of water repellency produced by a fire will ermine the subsequent management problems on the .

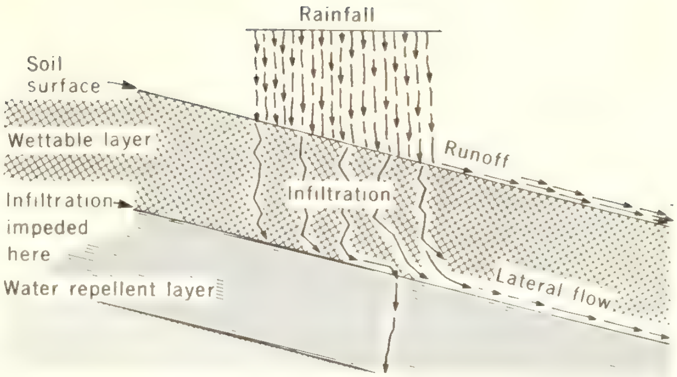


Figure 8—Water repellent layer impedes infiltration and causes surface runoff (DeBano 1969d).

Wildfires burning over coarse textured soil in both forests (DeByle 1973, DeBano 1969, Bashir 1969, Dyrness 1976) and brush areas (DeBano 1969a, 1979; Krammes and DeBano 1965; Reeder 1978; Vogl and Schorr 1972; Salih and others 1973; Wells and others 1979) can produce extreme water repellency. The water repellent soils formed during wildfires in chaparral areas in southern California (DeBano 1969c, 1974; DeBano and Rice 1971, 1973; Cleveland 1973; Foggin and DeBano 1971; Hays 1975; U.S. Department of Agriculture 1971) are considered partly responsible for the high rates of runoff and erosion from burned chaparral areas. On these burned areas, the soil at or near the surface may be wettable beneath which lies a layer of water repellent soil. This layered arrangement allows rainfall to infiltrate only a short distance before the wetting front encounters a water repellent layer (*fig. 8*). If the infiltrating water is impeded, or temporarily slowed down, then the thin mantle of wettable soil becomes saturated. Water then flows laterally and runs off, taking with it the soil from this upper layer along with some of the water repellent layer below. The amount of runoff and debris depends on the continuity and nature of the water repellent layer, steepness of slope, and intensity and amount of rainfall.

Solutions to Fire-Induced Water Repellency—Two methods are applied to manage water repellency caused by soil heating—improved infiltration and prescribed fire. Once water repellency is produced, such as during a wildfire, the management options available for improving infiltration are limited. The most common treatment has been with chemical wetting agents, although on small level areas the water repellent layer could perhaps be broken up by disking (DeBano and Rice 1973).

Prescribed fire, however, affords a more practical method of modifying water repellency by controlling the occurrence and behavior of fire, as opposed to permitting fuels to accumulate and burn by wildfire. Burning conditions could be prescribed in order to minimize water repellency. At present, sufficient knowledge is available about water repellency to develop general guidelines minimizing its impact. Given the less intense the fire, the finer the texture, the wetter the soil, and the smaller the quantities of organic matter on the soil surface, it follows that the less severe is the water repellency produced. These relationships allow prediction of how different soils, fire, and vegetation conditions may affect the production of water repellency.

The differences in fire intensity and soil heating during prescribed burning in forests, compared to brush areas, must be accounted for when predicting the possible impacts of fire on water repellency (DeBano and others 1979). Soil heating during brush fires is usually more severe than prescribed burns in forests, for several reasons (DeBano 1979). Both prescribed fires and wildfires are carried by the canopy and standing dead stems which leads to rapid and intense combustion, even during cooler prescribed fires in brush. In contrast, prescribed fires in forests are designed to minimize damage to standing trees (Biswell 1975) and are applied during moister conditions which restrict the fire to dead fuels. Chaparral fires usually burn only under drier conditions, when the live fuel moisture is low, so consequently both dead and live fuels are consumed during burning. Usually, the litter layer present in chaparral is thin, providing less efficient insulation against heat radiated downward during a fire. The forest floor duff and litter layer is normally thick, enhancing insulation against heat from fire. Consequently, chaparral fires create temperatures at and beneath the soil surface which generally are higher than corresponding temperatures caused by prescribed fires in forests (DeBano and Rice 1971).

Changes in chemical, physical, and biological properties of soils are minimized when less soil heating occurs. Water repellency problems are therefore less likely to develop after prescribed fires in forests; conversely, a higher incidence of water repellency is more likely to occur in chaparral areas. Several studies of prescribed burning in forests support this relationship. The broadcast burning of slash over a wet medium or fine textured soil did not produce enough water repellency to present a problem (DeByle 1973); however, in some ponderosa pine areas, even light prescribed burning can reduce significantly the initial infiltration rates (Zwolinski 1971). In some cases, light intensity fires may only concentrate water repellency in litter, thereby producing a negligible effect on the soil (Agee 1973). In chaparral areas, fire intensity may be decreased by burning during cooler times of the year when humidities are higher. Burning when the soils are moist would also minimize water repellency problems (DeBano and others 1976).

Treating the water repellent layer to make it wettable, such as with a wetting agent, reduces both runoff and erosion. Experiments on burned areas in southern California showed that runoff from untreated plots ranged from 4 to 10 cm during seasons when rainfall varied from 18 to 97 cm (Krammes and Osborn 1969). By comparison, plots treated with wetting agents yielded only 2- to 7-cm runoff under the same rainfall. Erosion was also reduced by about 40 percent with the wetting agent treatment. Although wetting agents were effective on small plots, they were extremely expensive and difficult to apply successfully on large areas (Rice and Osborn 1970). At present, the best solution seems to be prescribed fire—by burning with a light intensity fire or when the soil is moist—so that formation of water repellent soil is minimized.

Vegetation Management and Plant Establishment

Turf, Pasture, and Crop Management—The effect of water repellency on vegetation management was first described as the fairy ring phenomenon (Bayliss 1911, Shantz and Piemeisel 1917). This condition produces unsightly circular-shaped bare areas in otherwise healthy turf and lawns (Wilkinson and Miller 1978). Early folklore attributed these bare areas to the paths of dancing fairies, places where the devil churned his butter, the habitat of enormous toads with bulging eyes, and places where treasures were buried. Notwithstanding mythology, bare spots are actually places in the soil where dense fungal mycelia proliferated. The mycelia stimulate growth of grass for a short time which quickly exhausts the soil moisture. Once the soil is dry, the fungal growth prevents rewetting, that is, the soil becomes water repellent. An intense drought then kills the grass, leaving the area bare and subject to an invasion of weeds.

These fairy rings pose special and serious problems to the turf grass industry because a uniform, velvety green grass is esthetically desirable (Waddington 1969). Various preventive and corrective measures have been used to treat these localized dry spots. These practices are usually limited to cutting the grass short on putting greens, although aerating tools also have been used to break through the thatch and soil surface to improve uniformity of wetting. Topdressing with a good soil mixture, applied alone or in combination with mechanical aeration, has also been shown to decrease the incidence of these dry spots. Another approach improves the uniformity of wetting by applying wetting agents.

In Victoria, South Australia, and western Australia, water repellent soils present a problem in coarse-textured soils covering thousands of hectares (Bond 1960, 1964, 1965, 1968; Bond and Harris 1964). The soils in these Australian states support a grass cover on an annual rainfall of 64 cm or less. The pastures look patchy where well-grassed areas alternate with bare areas over small distances. Closer examination reveals that moisture penetrates only the grassed areas; the intervening bare patches are dry. These areas remain dry, even after rainstorms because the soil is extremely water repellent. The organic substances responsible for this water repellency are produced by microorganisms, particularly the basidiomycetes group of fungi (Bond

Harris 1964). Irregular wetting causes uneven ger-
tion and a patchy, less productive pasture. Various
e techniques are currently in use to reduce the ef-
of the repellency on crops and pastures (King
b). Cultivation during the rainy season sufficiently
ases water entry to allow germination and growth.
ther successful ameliorative measure involves sow-
ereals and pastures in furrows where rainwater can
entrate (Bond 1972).

ant Diseases—Water repellency is indirectly re-
isible for a disease called citrus decline. During
ights in Florida (Jamison 1942, 1946, 1947) and
pt (Bishay and Bakhati 1976), older trees in citrus
es sometimes drop their fruit, even after irrigating.
irrigation water wets only a small part of the soil in
oot zone beneath the branches. Organic material in
surface horizon was found to resist wetting. The
ace layer under the tree crown therefore acts like a
, shedding water to the wettable soil beyond the leaf
areas where it is less available to the tree roots.
ting the soil with polyacrylamide, a soil con-
ner, increased soil-water relations and improved
condition (Bishay and Bakhati 1976).

ed Germination and Plant Establishment—Water
llent soils can affect plant establishment on an area
educing the amount of water available for germina-
and growth or inducing overland flow and erosion
ch carries the seeds off the site before they can ger-
ate and become established. Laboratory exper-
nts using ryegrass have verified that germination and
blishment can be severely restricted by water repel-
soils and sands (Osborn and others 1967, Osborn
). The reduction in plant establishment was most
re when the test containers were placed on a 30-
ent slope, at which angle the runoff was more
ndant than in a level position, thereby reducing the
unt of water available for germination. Treating the
ing soils and sands with wetting agents increased
nination of the ryegrass and decreased runoff. Al-
ugh wetting agents favor ryegrass establishment, it
be at the expense of other plant species. For exam-
a study by DeBano and Conrad (1974) showed that
n a wetting agent was applied to a burned chaparral
ershed, germination and growth of ryegrass was fa-
ed, but it had a deleterious effect on mustards.

he resistance of forest litter to wetting may be re-
nsible for poor germination of important tree
cies. Tests using *Sequoiadendron giganteum* seeds
wed that when the litter surface resists wetting and
s quickly, a poor seedbed is produced (Stark 1968).
best condition for germination was found to be dis-
ed mineral soil in the shade.

r Problems

Vater repellent soils are created by the heat from
pfires (Fenn and others 1976). This condition ap-
red only in sandy soils which were initially moist and
se temperature remained below 350° C during the
campfire burn. If campfires were located randomly throughout the campsite, the harmful effect could be spread over a large part of the campground. Therefore, the harmful effect could be minimized if, as recommended, the campfires were restricted to the same area, even when permanent concrete fireplaces could not be installed; stone fire rings in a chosen location can accomplish the same objective.

RESEARCH NEEDS

Formation and Occurrence of Water Repellent Soils

Research of southern California chaparral has contributed substantially toward an understanding of water repellency and the relationships which exist between soil heating and organic matter, soil texture, and soil-water content. Future research should continue verifying and refining these relationships in other vegetation types. Moreover, water repellency measurements should be considered an integral part of fire-related studies. To this end, water repellency should be viewed in relation to other pertinent plant, fire, and soils data collected during fires.

A large gap exists in our understanding of microbially produced water repellency in chaparral, although the subject has been studied in other vegetation types. Microbially produced water repellency undoubtedly is present in chaparral and may function as part of the long-term ecological and successional aspects of this ecosystem, although little is known about this role. Future research in chaparral ecosystems perhaps will uncover some of the functional relationships governing the role of water repellency in mature chaparral stands.

Only a limited amount of information is available on the distribution of water repellent soils on wildland areas in the western United States (DeBano 1969a). A detailed survey of water repellent soils in California is however currently in preparation and will provide detailed information on the distribution of water repellency in California as related to the soil classification system used in the United States.

Chemistry of Hydrophobic Substances

Several research studies have examined the chemistry of both naturally occurring or fire-related hydrophobic substances, but this research has not revealed the detailed chemical make-up of the substances responsible for water repellency in unburned soils. The chemistry of hydrophobic substances produced by the heating of organic matter becomes more complex because an infinite number of organic compounds can be acted upon by fire to produce long chain, aliphatic hydrocarbons responsible for fire-induced water repellency. The difficulty in determining the complex chemical identity of the hydrophobic substances responsible for fire-induced water repellency probably restricts future studies in this area.

Soil-Water Movement

The theoretical principles underlying water movement in soils containing hydrophobic substances are adequately established. Currently, the largest gap in our knowledge is the application of these basic theories to a large-scale field situation where they can serve to describe the hydrology of entire watersheds or other management units. Logically, the first step in applying these basic principles to a watershed involves characterizing water repellency as a three-dimensional flow process, affected by three major features of the water repellent soil—intensity, thickness, and continuity of the water repellent layer. Any sampling procedure which is devised to quantify these features must necessarily be simple and not require excessive field sampling. In the simplest sampling scheme, the soil profile is merely exposed after a rainstorm, or an infiltrometer trial is made, and the horizontal and vertical distribution of the water repellent layer is mapped. Alternatively, a rapid sampling procedure could be developed by utilizing a few known relationships. For example, water repellency is restricted to areas where the surface of the soil is covered with heavy litter or where the subsoil layers contain decomposing roots. Knowledge of these relationships allows the thickness and intensity of the water repellent layer to be characterized easily and quickly at several locations by the waterdrop penetration time or critical surface tension. The thickness and intensity, once obtained, can be combined with plant cover data to develop a water repellency index for the site. Finally, the site index and pertinent hydrologic variables affecting runoff, such as slope, cover, drainage, and size, could be related to runoff on small plots or watersheds.

Vegetation Establishment and Growth

The germination and establishment of seedlings are affected by water repellent soils. Differences in competition between native and introduced species in water repellent soils particularly needs further study. The seeds of introduced species, mainly grasses, are easily moved downslope and tend to accumulate in small sheltered areas throughout the reseeded area. Native annuals, although sometimes irregularly distributed, apparently are not translocated as easily and are better able to seek out the discontinuities in the water repellent layer and become established, perhaps because they are covered more deeply by duff or soil. The resprouting perennial species probably are not affected directly by water repellency immediately after a fire. Although not yet studied, water repellency conceivably may affect the long-term ecology and water relations of chaparral ecosystems.

Runoff and Erosion

The relationship between erosion and water repellency is understood to some measure. When water repellent soils are treated with a wetting agent, runoff and erosion are usually reduced significantly because infiltration is more rapid; however, only a few cursory examinations of the wetting patterns of plots treated with wetting agents have been made. If wetting agent treatments are considered usable, the water transmitting ability of the soil profile in response to treatment must be better characterized; but, wetting agents currently are too expensive and logistically unsuited for wide scale application.

Runoff and erosion produced by water repellent soils probably contain large quantities of important plant nutrients. After a fire, the ashy soil surface contains a high concentration of highly soluble nutrients (DeBano and Conrad 1978). Surface runoff or downslope movement of debris undoubtedly carry nutrients, but only a few measurements of nutrient loss have been made during past studies (DeBano and Conrad 1976). Neither short- nor long-term nutrient losses have been related to the role of water repellency in the ecology of chaparral stands.

Research Needs in Southern California

Several water repellency problems remain unsolved; however, not all of these problems are of equal importance in terms of current management objectives for chaparral areas in southern California. A chief concern of current research in southern California is fuel modification and fire as a management tool. Because the regular use of fire is planned, special attention must be given to fire-related processes, for example, water repellency, nutrient loss, plant succession, runoff, and erosion. The priority issue confronting research is to characterize water repellency on a large-scale watershed basis in relation to runoff and erosion. A series of studies which would shift in scope from small plots to larger areas, and finally to watersheds would provide data relevant to developing and verifying a method for assessing water repellency on large areas. Such research, moreover, could be easily achieved within the context of concurrent studies on erosion and nutrient loss.

The prescribed burning studies would also provide excellent field testing of the interrelationships between

r repellency, soil texture, soil water, and fire inten-
With minimal effort, evaluations could be made of
ges in water repellency during fire. These changes
d then be related to variables measured as part of an
dy instrumented prescribed fire.

search Needs in Australia

he future research activities by Australian research-
have been reviewed by King (1974b). Research
ed at wetting the water repellent sand near seed and
roving the wettability of turf on bowling greens and
courses is planned. An intensive mapping of prob-
areas is also under consideration. Evaluations are
g made of surfactants, soil aggregating compounds,
different plant species as possible means of improv-
soil wettability. Finally, improving the productivity
hese lands can be expected only by imposing a re-
e dedicated to reversing the deleterious effects of
ient deficiencies, plant pathogens, water imbal-
es, erosion, and other yield-limiting factors.

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Water repellency in soils has worldwide implications. In some cases, special management problems are created; but in other situations, the principles of water repellency have been used to humankind's advantage. Most problems arise because of poor infiltration, difficulties in establishing plants, increased runoff and erosion, and plant diseases. An especially acute problem in southern California is the relationship between these soils and the high rates of runoff and erosion on freshly burned watersheds. Water repellent substances have been beneficial in harvesting water and reducing evaporation losses. These same substances provide a practical method of improving soil structure and aggregate stability. Much is known about the physics of water movement through these soils and the role of fire in their formation. This knowledge has not been formulated into management guidelines, although some general recommendations are available. Large gaps exist, however, in understanding the long-term role this soil condition has in the dynamics of forest, brush, and grassland ecosystems. As our knowledge of this discipline expands, more intelligent management of this soil property will evolve in both wildland and cultivated ecosystems.

Retrieval Terms: soil wettability, soil permeability, saturation resistance, water repellency, soil management

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International Directory of Documentation Services Concerning Forestry and Forest Products

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The Compilers:

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Acknowledgments:

Work on this directory was the result of the Station's Cooperative Agreement PSW-43 with the Department of Forestry and Resource Management, University of California. The principal investigator was Dr. John A. Helms. Processing of information was done on the University's UNIX computer system. The compilers appreciate the assistance of the UNIX staff. Particular appreciation is expressed to Alan G. Stangenberger, Department of Forestry and Resource Management, University of California, for his advice and troubleshooting with the UNIX, to Mike Vevea for initial training on UNIX, to Roger Sender for his many hours on the computer terminal, and to Doug Nielson for assistance in the preparation of Appendix A.

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

April 1981

ternational Directory of ocumentation Services oncerning Forestry and orest Products

ir A. Evans Gary L. Skupa *Compilers*

CONTENTS

Introduction ... 1

Explanation of Entry Format ... 2

Documentation Services ... 3

Indexes

Title ... 41

Acronyms and Title Abbreviations ... 45

Subject ... 46

Geographical Coverage ... 48

Country of Origin ... 49

Publishers and Issuing Organizations ... 52

Language(s) of Input Sources ... 54

Language(s) in Which Abstracts Are Published ... 55

Language(s) in Which Titles Are Published ... 55

Additional Services ... 55

Appendixes

A. Organizations Publishing an Acquisitions List ... 56

B. Questionnaire ... 62

lans for an international directory of documentation services concerning forestry and forest products nd back at least to FAO's 2d Expert Consultation on IS-Forestry in Rome, January 1975. Participants at neeting identified the need for "a catalog of scientific echnical information data bases related to forestry."[1] e recommendations were developed further at a shop in Madison, Wisconsin, in November 1975, and n at the 3d Technical Consultation on AGRIS-Forestry ancy, France, in June 1976. Studies called attention to e and Buntrock's *Survey of the World Agricultural umentation Services*[2] and to the work of others, but need was felt for a survey more closely aligned with try and forest products. In the fall of 1977, therefore, orest Service, U.S. Department of Agriculture, began operative agreement with the University of California semble and publish this directory.

e purpose of the directory is to provide an internal listing of documentation services concerning try and forest products, services that index and act the primary literature in the field. It differs from recent FAO publication, *AGRIS-Forestry, World logue of Information and Documentation Services*,[3] hat the FAO publication covers a wider range of try-related activities. In contrast, this directory lists those documentation services that meet the following irements:

- They must be an indexing, abstracting, or title service, or any combination of the three.
- Their output should be current and regular.
- There must be at least 100 citations per year.
- The service must be available in any one or more of the following forms: journals, sheets or pages, cards, microfiche, computer tape, printout from tape.
- Qualified users must be able to access the service through subscription, purchase, exchange, or some other common avenue; for example, membership, cooperative input, or other.
- At least 10 percent of the citations must be of interest for forestry, forest products, or related fields.

Although the compilers have used these six requirements as guidelines, they have deviated from them on occasion. Some services that publish on an irregular basis have been listed if their output appeared substantial and if documentation services from that geographical region were limited. Also, owing to the wide range of interests relative to forestry and forest products, the last requirement has been interpreted broadly. The compilers have preferred to list services in peripheral areas rather than ignore them if there is a possibility that the information is of interest to a forester.

This directory provides information about 120 documentation services in 28 countries.[4] Entry titles are arranged in alphabetical order in language of origin. All entries are indexed in these categories:

- Title (in language of origin, in English, by former title, by associated titles)
- Acronym and title abbreviation
- Subject
- Geographical coverage
- Country of origin
- Publisher or issuing organization
- Language(s) of input sources
- Language(s) in which abstracts are published
- Language(s) in which titles are published
- Additional services provided (beyond that of documentation).

It is hoped that this directory will be a useful contribution to the on-going development of an international information network for forestry and forest products.

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allaham, R.Z. "Scientific and technical data bases related to try." (Discussion paper) XVI IUFRO World Congress, Oslo, vay, 1976. Congress report, p. 335.

oyle, P.J., and H. Buntrock. *Survey of the World Agricultural umentation Services.* Luxembourg: Food and Agricultural Organin of of the United Nations, 1973.

rewer, Susan Lederer, compiler. *AGRIS Forestry World Catalogue formation and Documentation Services.* Rome: Food and Agriral Organization of the United Nations, 1979.

[4] For all but eight of the 120 entries, the information was supplied by the producer of the service in response to a questionnaire (*app. B*). The eight exceptions are marked with an asterisk in the listing of *Documentation Services.* These are documentation services which are well known but which did not respond to our questionnaire or services about which our information is incomplete. In these instances, the compilers of this directory, rather than the producer of the service, have supplied the information.

EXPLANATION OF ENTRY FORMAT

Although the appearance of entries will vary according to the nature of the service described, the information will generally consist of the following items:

A Title in language of origin
B Acronym or initials (when applicable)
C Title translated into English (will appear within parentheses when applicable)
D Type of service—journal, microfiche, tape, etc.—and cost. The cost is on the basis of 1977 figures. Although out of date, it is provided here as a basis of comparison. The figure in brackets is the cost of this service when provided outside the issuing country.
E Intial date of publication under current title
F Previous or associated titles
G Name and address of publisher, issuing organization, or both
H Subject coverage (See the subject index for fuller coverage
I Output information—number of citations, format, geographica coverage. Again, the figures are estimates on the basis of 1977 data out of date but still presumably useful for comparative purposes. (A service which provided 7000 citations in 1977 is still probably large than one which produced 170 citations in that year.) In the sectio labeled "*Format*," "full bibliographic coverage" means author, title volume, place of publication, publisher, and date of publication
J Input sources
K Indexes—type and frequency of publication
L Data handling
M Additional services—that is, in addition to documentation of the literature of forestry and forest products

Sample of entry format

A —— **ABSTRACT BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY** **ABIPC** —— B

C ——

D —— Journal, monthly, $750., [$750]; microfiche, monthly, $750., [$750] (lease agreement required); keyword index, monthly (except June) with semiannual cumulations, price not given; Sept. 1958- —— E

F —— **Previously published as:** BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY (1930-1958). *Contents overlap with:* PAPERCHEM (on-line version of ABIPC from July 1968 to present); IPC LIST OF TRANSLATIONS (free on request).

G —— **Published by:** The Institute of Paper Chemistry, 1043 E. South River Street, P.O. Box 1039, Appleton, Wis. 54912, U.S.A. *Issuing organization:* same as publisher. *Associated library:* Division of Information Services, The Institute of Paper Chemistry, 1043 E. South River Street, P.O. Box 1039, Appleton, Wis. 54912, U.S.A.

H —— **Subject coverage:** pulp, paper, and related subjects.

I —— **Output:** 300,000 citations through 1977 (11,143 abstracts, 478 cited titles in 1977). Arranged by subject first, then author. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, language of original text and of summaries. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

J —— **Input:** regularly scans 800 journals, 100 secondary sources. List of publications regularly scanned available. Almost all languages included. *Sources (percent):* journal articles (37), monographs (3), government documents and reports (1), conference papers (10), patents (40), secondary sources (5), translations (3), bibliographies and reviews (1).

K —— **Indexes:** *Author:* monthly, with annual cumulations. *Subject:* conventional alphabetical, monthly, with annual cumulations; about six terms per citation, controlled vocabulary, available for examination; thesaurus-based keyword index, monthly, with semiannual cumulations about 24 terms per citation, thesaurus available for examination. *Specific name index:* trade names, company names, and others; monthly, with annual cumulations. *Patent Number Index:* monthly, with annual cumulations.

L —— **Data handling:** computerized.

M —— **Additional services:** SDI and retrospective retrieval searches (through ORBIT); annotated bibliographic series; full-size copies; translation from all languages into English.

CUMENTATION SERVICES

ABI/INFORM

(Abstracted Business Information)

Magnetic tapes, monthly; contact Data Courier for price; 1978-

Published by: Data Courier, Inc., 620 South Fifth Street, Louisville, Ky. 40202, U.S.A. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: economics, management science, marketing, public administration, telecommunications, and other related subjects.

Output: about 72,000 citations through 1977 (18,218 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, CODEN, and ISSN. Titles in original language. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 400 journals. English. *Sources (percent):* journal articles (100).

Indexes: on-line searching can use words in title or abstract, keywords (eight to twelve per citation), author, CODEN, ISSN, and document type.

Data handling: computerized.

Additional services: on-line searching available through DIALOG, ORBIT, BRS, and Information Retrieval Service (European Space Agency); full-size copies.

ABSTRACT BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY **ABIPC**

Journal, monthly, $750., [$750]; microfiche, monthly, $750., [$750] (lease agreement required); keyword index, monthly (except June) with semiannual cumulations, price not given; Sept. 1958-

Previously published as: BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY (1930-1958). *Contents overlap with:* PAPERCHEM (on-line version of ABIPC from July 1968 to present); IPC LIST OF TRANSLATIONS (free on request).

Published by: The Institute of Paper Chemistry, 1043 E. South River Street, P.O. Box 1039, Appleton, Wis. 54912, U.S.A. *Issuing organization:* same as publisher. *Associated library:* Division of Information Services, The Institute of Paper Chemistry, 1043 E. South River Street, P.O. Box 1039, Appleton, Wis. 54912, U.S.A.

Subject coverage: pulp, paper, and related subjects.

Output: 300,000 citations through 1977 (11,143 abstracts, 478 cited titles in 1977). Arranged by subject first, then author. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, language of original text and of summaries. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 800 journals, 100 secondary sources. List of publications regularly scanned available. Almost all languages included. *Sources (percent):* journal articles (37), monographs (3), government documents and reports (1), conference papers (10), patents (40), secondary sources (5), translations (3), bibliographies and reviews (1).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* conventional alphabetical, monthly, with annual cumulations (about six terms per citation, controlled vocabulary, available for examination); thesaurus-based keyword index, monthly, with semiannual cumulations (about 24 terms per citation, thesaurus available for examination). *Specific name index:* trade names, company names, and others; monthly, with annual cumulations. *Patent Number Index:* monthly, with annual cumulations.

Data handling: computerized.

Additional services: SDI and retrospective retrieval searches (through ORBIT); annotated bibliographic series; full-size copies; translation from all languages into English.

ABSTRACT INFORMATION DIGEST SERVICE **AIDS**

Microfiche, semiannual; magnetic tapes, semiannual; price not given; 1974-

Contents overlap with: WOOD INDUSTRY ABSTRACTS.

Published by: Forest Products Research Society, 2801 Marshall Court, Madison, Wis. 53705, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: forest products.

Output: 10,109 citations through 1977 (1200 to 1500 citations in 1977). Arranged by subject. *Format:* full bibliographic citations plus keywords, subject headings, species, and author affiliation. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 350 journals, 200 secondary sources. List of publications regularly scanned available for examination. English and non-English articles that include English abstract and title. *Sources (percent):* journal articles (60), government documents and reports (29), conference papers (1), patents (10).

Indexes: *Author:* semiannual. *Subject:* KWOC, semiannual (10 to 15 terms per citation, controlled vocabulary, available for examination). *Taxonomic:* semiannual.

Data handling: computerized and mechanical.

Additional services: retrospective retrieval searches; full-size copies; abstract copies.

4 ABSTRACTS—U.S. INTERNATIONAL BIOLOGICAL PROGRAM ECOSYSTEM ANALYSIS STUDIES — US/IBP ABSTRACTS

Journal, irregularly, free; computer printout, microforms, and magnetic tapes by request only, free; 1972-

Previously published as: ABSTRACTS—U.S.-IBP ECOSYSTEM ANALYSIS STUDIES (1972); BIOME ABSTRACTS—U.S.-IBP ECOSYSTEM ANALYSIS (1972); U.S.-IBP Analyses of Ecosystems Program Interbiome Abstracts (1971); U.S./IBP Abstracts (1970). *Contents cumulate into:* ORLOOK (on-line retrieval file).

Published by: Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, Tenn. 37830, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: ecology of coniferous forests, deserts, Eastern deciduous forests, grasslands and tundras in the United States.

Output: (950 abstracts in 1977). Arranged by authors within biome groups. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, taxonomic names, geographic descriptors and data collection information (such as dates of research and parameters measured). Titles in English. Abstracts in English. *Geographic coverage:* United States: Coniferous Forest Biome, Desert Biome, Eastern Deciduous Forest Biome, Grassland Biome, Tundra Biome.

Input: regularly inputs reports and datasets of the US/IBP biomes (Coniferous Forest Biome, Desert Biome, Eastern Deciduous Forest Biome, Grassland Biome, and Tundra Biome). English; occasionally French, German, or Russian. *Sources (percent):* journal articles (60), monographs (10), government documents and reports (25), conference papers (5).

Indexes: *Author:* every issue, with cumulations every four issues. *Subject:* KWOC, every issue, with cumulations every four issues (6 to 10 terms per citation, controlled vocabulary, available for examination). *Geographic:* every four issues.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, numeric data sets from the Eastern Deciduous Forest Biome Studies.

5 *ABSTRACTS OF BULGARIAN SCIENTIFIC LITERATURE (AGRICULTURE AND FORESTRY, VETERINARY MEDICINE)

SERIES A: PLANT BREEDING AND FOREST ECONOMY

Journal, quarterly, price not given; 1956-

Published by: National Center for Scientific and Technical Information in Agriculture, Food Industry and Forestry, Sofia, 6 Dragan Tsankov Blvd., Bulgaria: *Issuing organization:* same as publisher.

Subject coverage: agriculture, soil science, and forestry in Bulgaria.

Output: editions published in English and in Russian. (870 abstracts in 1978). Arranged by subject categories. *Format:* full bibliographic citations plus abstracts, authors' addresses, and names of abstracters. Titles in Bulgarian, and in English or Russian. Abstracts in English or Russian. *Geographic coverage:* Bulgaria.

Input: items on plant breeding and forest economy published in Bulgaria. Bulgarian. *Sources (percent):* journal articles (~100).

Indexes: *Author:* quarterly. *Subject:* quarterly.

6 ABSTRACTS OF ENTOMOLOGY

Journal, monthly, $95. [$95.], plus $35. [$35.] for the annual cumulative index; 1970-

Contents cumulate into: BIOSIS PREVIEWS. *Contents selected from:* BIOLOGICAL ABSTRACTS and BIORESEARCH INDEX.

Published by: Biosciences Information Service (BIOSIS), 2100 Arch Street, Philadelphia, Pa. 19103, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: entomology.

Output: 115,000 abstracts through 1977 (13,000 abstracts in 1977). Arranged by reference number originally assigned to items when listed for Biological Abstracts and BioResearch Index. *Format:* full bibliographic citations plus abstracts, keywords, authors' addresses, CODEN and ISBN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 8000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles plus government documents and reports (94), monographs (1), conference papers (5).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* title words in context, preceded or followed, or both, by other keywords not in context; permuted format, monthly, with annual cumulations (about 19 terms per citation.) *Taxonomic:* Generic Index (genus and species); Biosystematic Index (above genus level). *Other:* Concept Index (more than 500 broad subject headings in biology).

Data handling: computerized.

ABSTRACTS OF MYCOLOGY

Journal, monthly, $75. [$75.], plus $30. [$30.] for the annual cumulative index; 1967-

Contents cumulate into: BIOSIS PREVIEWS. *Contents selected from:* BIOLOGICAL ABSTRACTS and BIORESEARCH INDEX.

Published by: Biosciences Information Service (BIOSIS), 2100 Arch Street, Philadelphia, Pa. 19103, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: mycology.

Output: 120,000 abstracts through 1977 (12,500 abstracts in 1977). Arranged by reference number originally assigned to items when listed for Biological Abstracts and BioResearch Index. (BA items first, followed by BioI items). *Format:* full bibliographic citations plus abstracts, keywords, authors' addresses, CODEN and ISBN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 8000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles plus government documents and reports (94), monographs (1), conference papers (5).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* title words in context, preceded or followed, or both, by other keywords not in context; permuted format, monthly, with annual cumulations (about 19 terms per citation). *Taxonomic:* Generic Index (genus and species); Biosystematic index (above genus level). *Other:* Concept Index (more than 500 broad subject headings in biology).

Data handling: computerized.

ABSTRACTS ON HEALTH EFFECTS OF ENVIRONMENTAL POLLUTANTS HEEP

Journal, monthly, $120. [$120.], plus $50. [$50.] for the annual cumulative index; 1972-

Contents cumulate into: BIOSIS PREVIEWS. *Contents selected from:* BIOLOGICAL ABSTRACTS and BIORESEARCH INDEX.

Published by: Biosciences Information Service (BIOSIS), 2100 Arch Street, Philadelphia, Pa. 19103, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: environmental pollution and its effects on health.

Output: 75,000 abstracts through 1977 (13,500 abstracts in 1977). Arranged by reference number originally assigned to items when listed for Biological Abstracts and BioResearch Index (BA items first, followed by BioI items). *Format:* full bibliographic citations plus abstracts, keywords, authors' addresses, CODEN and ISBN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 8000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles plus government documents and reports (94), monographs (1), conference papers (5).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* title words in context, preceded or followed, or both, by other keywords not in context; permuted format, monthly, with annual cumulations (about 19 terms per citation). *Taxonomic:* Generic Index (genus and species); Biosystematic Index (above genus level). *Other:* Concept Index (more than 500 broad subject headings in biology).

Data handling: computerized.

ABSTRACTS ON TROPICAL AGRICULTURE ATA

Journal, monthly, Dfl. 235., $120. [Dfl. 235., $120.]; card service, monthly, price per card: Dfl. 0.20, $.10; 1975-

Previously published as: TROPICAL ABSTRACTS (1946-1974).

Published by: Koninklijk Instituut voor de Tropen, (Royal Tropical Institute), Department of Agricultural Research, Mauritskade 63, 1092 AD Amsterdam, Netherlands. *Issuing organization:* same as publisher. *Associated library:* Koninklijk Instituut voor de Tropen, Centrale Bibliotheek, Mauritskade 63, 1092 AD Amsterdam, Netherlands.

Subject coverage: tropical agriculture.

Output: 18,137 citations through 1977 (6000 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, primary authors' addresses, ISSN, ISBN and language of item. Titles in original language and English. Abstracts in English. *Geographic coverage:* tropical and subtropical regions.

Input: regularly scans 1500 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), monographs (10), government documents and reports (10), conference papers (10).

Indexes: *Author:* monthly. *Subject:* monthly, with annual cumulations (about 5 terms per citation). *Geographic:* monthly. *Taxonomic:* annual (plants only). *Author affiliation:* monthly.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies.

10 ACCESSIONS BULLETIN

Journal, every 3 weeks, free, 1958-

Published by: Library, Tropical Products Institute, 56-62 Grays Inn Road, London WC1X 8LU, England. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: products of tropical agriculture, including forest products.

Output: about 675,000 citations through 1977 (3811 citations printed, 16,000 citations compiled in 1977). Arranged by author. *Format:* full bibliographic citations plus ISBN, and UDC for nonserial monographs. Titles in English. *Geographic coverage:* worldwide, with emphasis on developing countries.

Input: regularly scans 1200 journals. List of publications regularly scanned available for examination. English, French, Spanish, German, Portuguese. *Sources (percent):* journal articles (30), monographs (30), government documents and reports (30), conference papers (5), patents (1), other (4).

Data handling: manual.

Additional services: retrospective retrieval searches, full-size copies, library loans (to U.K. libraries only). Translation services from French, German, and Spanish into English.

11 AGRARMETEOROLOGISCHE BIBLIOGRAPHIE 19__
(AGRICULTURAL METEOROLOGY BIBLIOGRAPHY)

Journal, monthly, DM 42, —; 1950-

Published by: Deutscher Wetterdienst, Zentralamt, Frankfurter Str. 135, 6050 Offenbach a.M., Bundesrepublik Deutschland. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: agricultural meteorology.

Output: 40,000 citations through 1977 (1800 abstracts, 2100 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts. Titles in original language and in German, English, or French. Abstracts in German, English, or French. *Geographic coverage:* worldwide.

Input: regularly scans 1500 journals, 15 secondary sources. German, English, and French. *Sources (percent):* journal articles (70), monographs (30).

Indexes: *Author:* annual. *Subject:* annual (about three terms per citation).

Data handling: manual.

12 AGRIASIA: A CURRENT BIBLIOGRAPHY OF SOUTHEAST ASIAN AGRICULTURAL LITERATURE — AGRIASIA

Journal, every 4 months, P240, $35. [U.S. $60.]; magnetic tapes, every 4 months, price not given; 1977-

Contents overlap with: NATIONAL AGRICULTURAL BIBLIOGRAPHY SERIES.

Published by: Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), College, Laguna 3720, Philippines. *Issuing organization:* Agricultural Information Bank for Asia, College, Laguna 3720, Philippines. *Associated libraries:* Bangladesh National Scientific and Technological Documentation Centre; Agriculture and Fisheries Department, Canton Road Government Offices (Hong Kong); Bibliotheca Bogoriensis (Indonesia); Perpustakaan Negara Malaysia; University of the Philippines at Los Banos Library; Korea Scientific and Technological Information Centre (South Korea); Nanyang University (Singapore); and Thai National Documentation Centre.

Subject coverage: agriculture.

Output: (4387 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus keywords, subject headings, source, authors' addresses, ISSN and ISBN. Titles in original language and English. *Geographic coverage:* Asia (Bangladesh, Hong Kong, Indonesia, Malaysia, Philippines, Republic of Korea, Singapore, and Thailand).

Input: regularly scans 279 journals, 10 secondary sources. English, Thai, Bahasa-Indonesian, Malay, Filipino, Korean, Chinese. *Sources (percent):* journal articles (30), monographs (20.5), government documents and reports (0.5), conference papers (14), other (35).

Indexes: *Author:* every 4 months. *Subject:* KWIC, every 4 months. *Geographic:* every 4 months. *Other:* index to scientific names.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, microcopies.

AGRICultural On-Line Access **AGRICOLA**

Magnetic tapes, monthly, $45 [$45.]; 1976-

Previously published as: CAIN [CAtaloging and INdexing Records] (1970-1976). *Contents overlap with:* BIBLIOGRAPHY OF AGRICULTURE, the NATIONAL AGRICULTURAL LIBRARY CATALOG, and the AG-ECON database.

Issuing organization: U.S. Department of Agriculture, Science and Education Administration, Technical Information Systems, Resource Development Division, NAL Building, Beltsville, Md. 20705, U.S.A. *Associated library:* National Agricultural Library, SEA/TIS, U.S. Department of Agriculture, Beltsville, Md. 20705, U.S.A.

Subject coverage: agriculture.

Output: 1,024,197 citations through 1977 (144,358 cited titles in 1977). Output arrangement determined by online search strategy. Database searchable by keywords, subject headings, subject category codes, author, corporate author, date of publication, date of indexing, document type, geographic codes, journal title abbreviations, language, and source codes. *Format:* full bibliographic citations plus keywords, subject headings, subject categories, ISSN, ISBN, language of item, and summaries for foreign articles. Titles in original language and English. *Geographic coverage:* worldwide.

Input: regularly scans 7000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (77), monographs (10), government documents and reports (5), conference papers (8).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, library loans.

AGRINDEX

Journal, monthly, $250. [$250.]; magnetic tapes (AGRIS), monthly, only available to AGRIS participating centers (distribution policy in process of being defined); 1975-

Contents cumulate into: AGRIS[5].

Published by: APIMONDIA, St. Pitar Mos no. 20,. Bucaresti, Romania (main office); APIMONDIA, Corso Vittorio Emanuele 101, 00186 Roma, Italy. *Coordinating organization:* AGRIS Coordinating Centre, FAO, Via delle Terme di Caracalla, 00100 Roma, Italy. *Associated libraries:* AGLINET Libraries (Worldwide Network of Agricultural Libraries), listed in each issue.

Subject coverage: agriculture.

Output: 223,045 citations through 1977 (97,666 cited titles in 1977). Arranged by subject categories (headings) and commodity codes (subheadings). *Format:* full bibliographic citations plus subject categories, source, authors' affiliations, ISSN, ISBN, availability statement for nonconventional documents, language of text, commodity codes and geographic codes. Titles in original language and English. Abstracts in any language as submitted for inclusion on AGRIS tapes. *Geographic coverage:* worldwide.

Input: regularly scans 5000 journals. Almost all languages included. *Sources:* journal articles, monographs, dissertations and theses, government documents and reports, conference papers, patents, nonconventional literature.

Indexes: *Author:* monthly, with cumulations every 2 years (except 3-yr. index for 1975-1977). *Subject:* AGRIS classification scheme, monthly, with cumulations every 2 years (except 3 yr. index for 1975-1977); (controlled vocabulary, available for examination). *Other:* commodities index, corporate authors index, and report and patent number index.

Data handling: computerized.

Additional services: (provided by AGLINET Libraries): full-size copies, microcopies, library loans, translations.

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[5] AGRINDEX (printed product) and AGRIS tapes have the same subject contents. The tape version also includes data related to geographic subject aspects, document type, literary indicators, and others for which no indexes are included in the printed version. From 1979 onwards, input by participating centers of index terms and/or abstracts is allowed but not compulsory. These are recorded on AGRIS tapes only.

15 AIKAKAUSLEHTIKATSAUS—TIDSKRIFTSOVERSIKT (WEEKLY SURVEY OF PERIODICALS)

Offset-printed list, weekly, mk 200.—; 1947-

Published by: Oy Keskuslaboratorio—Centrallaboratorium Ab, (The Finnish Pulp and Paper Research Institute), Documentation Service, P.O. Box 136, SF—00101 Helsinki 10, Finland. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: forestry and forest products.

Output: 45,000 citations from 1974 through 1977 (11,000 citations printed in 1977). *Format:* bibliographic citations plus subject headings. Titles in original language, except for Japanese and Slavic language citations. *Geographic coverage:* worldwide.

Input: regularly scans 330 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (80), conference papers (10), patents (10).

Data handling: manual.

Additional services: SDI, retrospective retrieval searches, full-size copies. Translation services: from Finnish and Swedish into English and German.

16 APPLIED ECOLOGY ABSTRACTS: STUDIES IN RENEWABLE NATURAL RESOURCES — AEA

Journal, monthly, £80, $160. [in U.S.A. and Canada, U.S. $235.; elsewhere, £90]; magnetic tapes, price and frequency not given; 1975-

Published by: Information Retrieval Limited, 1 Falconberg Court, London W1V 5FG, U.K. (U.S.A. Office—Information Retrieval, Inc., 1911 Jefferson Davis Highway, Arlington, Va. 22202, U.S.A.) *Issuing organization:* same as publisher.

Subject coverage: ecology, including forest ecology, silviculture, forest management, insects, disease, and damage.

Output: 36,186 citations through 1977 (14,000 abstracts, 900 cited titles printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, price, authors' addresses, ISSN, ISBN, and language of original item and any summaries given. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 5000 journals, 300 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (55), monographs (15), government documents and reports (15), conference papers (10), secondary sources (3), other (5)

Indexes: *Author:* monthly, with annual cumulations. *Subject:* keywords linked in chains (modified A.S.I. type), monthly, with annual cumulations (about six terms per citation, controlled vocabulary, available for examination). *Geographic:* monthly. *Taxonomic:* included as part of subject index.

Data handling: computerized and manual.

Additional services: SDI, reprints of journal articles.

17 AQUATIC SCIENCES AND FISHERIES ABSTRACTS— PART 1: BIOLOGICAL SCIENCES AND LIVING RESOURCES — ASFA PART 1

Journal, monthly, £105. U.K. and India. [£115 elsewhere]; magnetic tapes, monthly, contact FAO for details; 1978-

Previously published as: AQUATIC SCIENCES AND FISHERIES ABSTRACTS (1971-1977) was formed when AQUATIC BIOLOGY ABSTRACTS and CURRENT BIBLIOGRAPHY FOR AQUATIC SCIENCES AND FISHERIES were merged in 1971. *Contents cumulate into:* AQUATIC SCIENCES AND FISHERIES INFORMATION SYSTEM (ASFIS).

Published by: Information Retrieval Limited, 1 Falconberg Court, London W1V 5FG, United Kingdom. *Issuing organization:* Food and Agriculture Organization of the United Nations, Via delle Terme di Caracalla, Rome, Italy.

Subject coverage: aquatic biology and fisheries.

Output: (16,000 abstracts printed in 1978). Arranged by subject categories. *Format:* full bibliographic citations plus abstracts, first author's affiliation and language of item and any summaries. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 5000 journals. Almost all languages included.

Indexes: *Author:* monthly with annual cumulations. *Subject:* rotated-chain keyword, monthly, with annual cumulations (controlled vocabulary). *Geographic:* monthly, with annual cumulations. *Taxonomic:* monthly, with annual cumulations.

Data handling: computerized.

ASSISTANCE WITH ARBORICULTURAL READING

Sheets, weekly, £5 [£5]; 1977-

Contents overlap with: ASSISTANCE WITH RESEARCH READING.

Published by: Arboricultural Advisory and Information Service, Forestry Commission Research Station, Alice Holt Lodge, Wrecclesham, Farnham, Surrey GU10 4LH, England. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: arboriculture.

Output: 1000 citations printed in 1977. Arranged by titles of primary journals or sources scanned. *Format:* bibliographic citations. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 1000 journal issues per year. List of publications regularly scanned available for examination. English, French, German, and Dutch. *Sources (percent):* journal articles (100).

Data handling: manual.

Additional services: full-size copies.

BIBLIOGRAFIA AGROPECUARIA VENEZOLANA

Journal, semiannual, price not given; 1975-

Contents cumulate into (as cooperative input): AGRIS, AGRINTER, and EL INDICE AGRICOLA DE AMERICA LATINA Y EL CARIBE.

Published by: Orfila Marquez y Dilia Ramos, CENIAP, Biblioteca, Aptdo. 4653, Maracay, Estado Aragua, Venezuela. *Issuing organization:* Red de Informacion para las Ciencias Agropecuarias (REDIAGRO), Aptdo. 4653, Maracay, Estado Aragua, Venezuela. *Associated library:* Biblioteca, CENIAP, Aptdo. 4653, Maracay, Estado Aragua, Venezuela.

Subject coverage: agriculture in Venezuela.

Output: (683 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus subject headings and source. Titles in original language. *Geographic coverage:* Venezuela.

Input: Spanish. *Sources (percent):* monographs (25), government documents and reports (50), conference papers (25).

Indexes: *Author:* semiannual. *Subject:* semiannual (4 to 6 terms per citation, controlled vocabulary, available for examination).

Data handling: manual.

Additional services: full-size copies, library loans.

BIBLIOGRAFIA BRASILEIRA DE BOTANICA (BRAZILIAN BIBLIOGRAPHY OF BOTANY)

Book, approximately annual, Cr. $100. [U.S. $13.]; V.1 1950-55

Published by: Instituto Brasileiro de Informacao em Ciencia e Tecnologia (IBICT), Av. General Justo 171– 4o andar—20021—Rio de Janeiro, RJ, Brasil. *Issuing organization:* same as publisher. *Associated library:* Biblioteca do IBICT, Av. General Justo 171—terreo —20021—Rio de Janeiro, RJ, Brasil.

Subject coverage: botany.

Output: 4200 cited titles throughout 1977 (600 cited titles in 1977). Arranged by number. *Format:* full bibliographic citations plus keywords and subject headings. Titles in original language. *Geographic coverage:* Brazil.

Input: regularly scans 47 journals. List of publications regularly scanned available for examination. Mostly Portuguese. *Sources (percent):* journal articles (60), monographs (30), conference papers (10).

Indexes: *Author:* annual. *Subject:* KWIC, annual (about five terms per citation, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: full-size copies, microcopies.

BIBLIOGRAFIA BRASILEIRA DE CIENCIAS AGRICOLAS (BRAZILIAN BIBLIOGRAPHY OF AGRICULTURAL SCIENCES)

Book, approximately annual, Cr. $400 [U.S. $25.]; 1967/ 68-

Previously published as: BIBLIOGRAFIA BRASILEIRA DE AGRICULTURA (1956 58-1965-66?).

Published by: Instituto Brasileiro de Informacao em Ciencia e Tecnologia (IBICT), Av., General Justo 171 —4o andar—20021—Rio de Janeiro, RJ, Brasil. *Issuing organization:* same as publisher. *Associated library:* Biblioteca do IBICT, Av., General Justo 171—terreo —20021—Rio de Janeiro, RJ, Brasil.

Subject coverage: agricultural sciences in Brazil.

Output: 24,000 cited titles through 1977 (3200 cited titles in 1977). Arranged by index number. *Format:* full bibliographic citation plus keywords and subject headings. Titles in original language. *Geographic coverage:* Brazil.

Input: regularly scans 61 journals. List of publications regularly scanned available for examination. Mostly Portuguese. *Sources (percent):* journal articles (60), monographs (30), conference papers (10).

Indexes: *Author:* annual. *Subject:* KWIC, annual (about five terms per citation, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: full-size copies, microcopies.

22 BIBLIOGRAFIA BRASILEIRA DE ZOOLOGIA
(BRAZILIAN BIBLIOGRAPHY OF ZOOLOGY)

Book, approximately annual, Cr. $200 [U.S. $16.]; V. 1 1950/55-

Published by: Instituto Brasileiro de Informacao em Ciencia e Tecnologia (IBICT), Av., General Justo 171 — 4o andar— 20021 — Rio de Janeiro, RJ, Brasil. *Issuing organization:* same as publisher. *Associated library:* Biblioteca do IBICT, Av., General Justo 171 — terreo — 20021 — Rio de Janeiro, RJ, Brasil.

Subject coverage: zoology.

Output: 6033 cited titles through 1977 (853 cited titles in 1977). Arranged by number. *Format:* full bibliographic citations plus keywords and subject headings. Titles in original language. *Geographic coverage:* Brazil.

Input: regularly scans 37 journals. List of publications regularly scanned available for examination. Mostly Portuguese. *Sources (percent):* journal articles (60), monographs (30), conference papers (10).

Indexes: *Author:* annual. *Subject:* KWIC, annual (about 5 terms per citation, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: full-size copies, microcopies.

23 BIBLIOGRAFIA EN CIENCIAS FORSTALES BCF
(BIBLIOGRAPHY ON FOREST SCIENCES)

Book, irregular, Argentine $240.000.—, U.S. $200. [Arg. $264.000.—, U.S. $220.]; card service, price and frequency not given; 1978?-

Published by: Centro de Informacion Bioagropecuario y Forestal, Direccion de Bibliotecas, Universidad Nacional de Nordeste, Av. Las Heras 727, 3.500 Resistencia—Chaco—Argentina. *Issuing organization:* same as publisher. *Associated library:* Instituto Forestal Nacional, Pueyrredon 2446, 1119 Buenos Aires —Argentina.

Subject coverage: forestry and forest products.

Output: (26,950 citations compiled, 16,400 printed in 1978). Arranged by subject, author. *Format:* full bibliographic citations plus keywords, source and subject headings. Titles in original language. *Geographic coverage:* worldwide.

Input: regularly receives input from 11 participating centers. Mostly Spanish and English. *Sources (percent):* monographs (20), government documents and reports (5), conference papers (5), secondary sources (70).

Indexes: *Author:* annual; *Subject:* KWIC, annual, (controlled vocabulary, available for examination).

Data handling: manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, library loans, Translation services: from English into Spanish, from German into Spanish.

24 BIBLIOGRAPHIE DER PFLANZENSCHUTZ-LITERATUR, NEUE FOLGE
(BIBLIOGRAPHY OF PLANT PROTECTION LITERATURE, NEW SERIES)

Journal, every 4 months, DM. 220 [DM.220]; (original series, 1921-1967) 1968-

Published by: Paul Parey, Zindenstr. 44-47, D1000 Berlin 61, Federal Republic of Germany. *Issuing organization:* Dokumentationsschwerpunkt, Pflanzenkrankheifen und Pflanzenschutz der Biologischen Bundesanstalt fur Land und Forstwirtschaft, 1 Berlin 33 Dahlem, Konigin-Luise-Strasse 19, Federal Republic of Germany. *Associated libraries:* Bibliothek der Biologischen Bundesanstalt fur Land und Forstwirtschaft, Konigin-Luise-Strasse 19, 1000 Berlin 33, Germany; and Dokumentationsschwerpunkt, Pflanzenkrankheifen und Pflanzenschutz der Biologischen Bundesanstalt fur Land- und Forstwirtschaft, 1 Berlin 33 Dahlm, Konigen-Luise-Strasse 19, Federal Republic of Germany.

Subject coverage: plant pathology and plant protection, including pesticides and breeding for resistance.

Output: 176,000 citations through 1977 (16,000 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus subject headings. Titles in original langauge and German or English or French. *Geographic coverage:* worldwide.

Input: regularly scans 1500 journals. Almost all languages included. *Sources (percent):* journal articles (80), monographs (5), government documents and reports (2), conference papers (10), other (3).

Indexes: *Author:* every 4 months, with annual cumulations. *Subject:* every 4 months, with annual cumulations (about 8 terms per citation, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: retrospective retrieval searches, full-size copies, library loans.

IBLIOGRAPHY OF IRRIGATION, DRAINAGE, RIVER TRAINING AND FLOOD CONTROL (BIBLIOGRAPHIE RELATIF AUX IRRIGATIONS, AU DRAINAGE, A LA REGULARISATION DES COURS D'EAU ET LA MAITRISE DES CRUES)

Book, annual, $2.50 [$2.50]; 1954/56-

Published by: Secretary-General, International Commission on Irrigation and Drainage (ICID), 48 Nyaya Marg, Chanakyapuri, New Dehli 110021, India. *Issuing organization:* same as publisher.

Subject coverage: irrigation, drainage, river training and flood control.

Output: (2069 abstracts in 1977). Arranged by ODC classification. *Format:* full bibliographic citations plus some digests, keywords, subject headings, and ODC classification. Titles translated into English, except French titles. Digests in English. *Geographic coverage:* ICID member countries (almost worldwide).

Input: regularly scans 200 journals, 20 secondary sources. List of publications regularly scanned published at end of bibliography. Almost all languages included. *Sources (percent):* Journal articles (70), monographs (11), government documents and reports (4), conference papers (10), secondary sources (5).

Indexes: *Author:* annual. *Subject:* KWOC, annual (two or three terms per citation, controlled vocabulary, available for examination).

Data handling: manual.

BIBLIOGRAPHY OF SYSTEMATIC MYCOLOGY

Journal, semiannual, £4.50 in Commonwealth [$8 for non-Commonwealth countries]; 1947-

Published by: Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, Slogh SL2 3BN, England. *Issuing organization:* Commonwealth Mycological Institute, Ferry Lane, Kew, Surrey TW9 3AF, England. *Associated library:* Library, Commonwealth Mycological Institute, Ferry Lane, Kew, Surrey, TW9 3AF, England.

Subject coverage: mycology.

Output: 26,240 citations through 1977 (1256 citations printed in 1977). Arranged by country and systematic group with cross-references. *Format:* bibliographic citations plus price (for books) and geographic cross-references (newly published taxa when appropriate). Titles in English for transliterated and East European citations; otherwise in original language). *Geographic coverage:* worldwide.

Input: regularly scans 1472 journals, six secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (85), monographs (5), government documents and reports (5), conference papers (5).

Indexes: *Author:* semiannual, with 5-year cumulations. *Subject:* semiannual, with 5-year cumulations.

Data handling: manual.

Additional services: full-size copies, library loans.

BILIMSEL VE TEKNIK YAYINZAR AYLIK DUYURU BULTENI (CURRENT TITLES IN TURKISH SCIENCE)

Journal, monthly, free; 1976-

Previously published as: TEMEL VE UYGULAMALI BILIMLER AYLIK BIBLIYOGRAFYA DUYURUSU (1974-75); KEY TO TURKISH SCIENCE (1968-71). *Contents overlap with:* CURRENT TITLES IN TURKISH SCIENCE, the English version of BILIMSEL VE TEKNIK . . .

Published by: TUBITAK TURDOK, Ataturk Bulvari no. 221, Kavaklidere, Ankara, Turkey. *Issuing organization:* same as publisher. *Associated library:* Turkiye Bilimsel ve Teknik Dokumantasyon Merkezi (TURDOK), Turkish Scientific and Technical Documentation Center, Ataturk Bulvari no. 221, Kavaklidere, Ankara, Turkey.

Subject coverage: science in Turkey, or science related to Turkey.

Output: (110 cited titles related to forestry and forest products in 1977). Arranged by subject. *Format:* full bibliographic citations plus keywords. Titles in original language and Turkish. *Geographic coverage:* Turkey.

Input: regularly scans 350 primary sources. Turkish, German, English and French. *Sources (percent):* journal articles (85), monographs (5), government documents and reports (5), conference papers (5).

Indexes: *Author:* annual. *Subject:* annual (about three terms per citation).

Data handling: manual.

Additional services: retrospective retrieval searches, full-size copies.

BILTEN DOKUMENTACIJE—[SERIJA D4]—INDUSTRIJA TEKSTILA I PAPIRA (BULLETIN OF DOCUMENTATION—SERIES D4—TEXTILE AND PAPER INDUSTRY)

Journal, monthly, 3,850.-din., $385. [$385.]; card service, irregular, price not given; microforms, irregular, price not given; 1951-

Published by: Jugoslovenski Centar za Technicku i Naucnu Dokumentaciju, 11,000 Beograd, Sl. Penezica-Krcuna br. 29-31, P. Box 724, Yugoslavia. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: pulp and paper.

Output: 11,000 citations through 1977 (430 abstracts printed, of 500 citations compiled in 1977). Arranged by subject, keywords and UDC system. *Format:* bibliographic citations plus abstracts, keywords, and UDC. Titles in original language and Serbo-Croation. Abstracts in Serbo-Croation. *Geographic coverage:* Europe and North America.

Input: regularly scans 25 journals. English, French, German, Russian, Romanian, Hungarian, Polish and Czechoslovakian. *Sources (percent):* journal articles (95 to 98), secondary sources (2 to 5).

Indexes: *Subject:* UDC, monthly (about 5 terms per citation).

Data handling: manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies. Translation services: from English, French, German, Russian, Romanian, Hungarian, Polish and Czechoslovakian into Serbo-Croatian.

29 BILTEN DOKUMENTACIJE—[SERIJA A 3]— SUMARSTVO I DRVNA INDUSTRIJA (BULLETIN OF DOCUMENTATION—SERIES A 3— FORESTRY AND WOOD INDUSTRY)

Journal, monthly, 3,850 Dinars, $385 [$385.]; card service, price and frequency not given; microforms, price and frequency not given; 1952-

Published by: Jugoslovenski centar za technicku i naucnu dokumentaciju, 11000 BEOGRAD, Slobodana Penezica-Krcuna 29-31; POB 724, Yugoslavia. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: forestry and forest products.

Output: (1760 abstracts printed, 2000 citations compiled in 1977). Arranged by UDC *Format:* full bibliographic citations plus abstracts and keywords. Titles in original language and Serbo-Croatian. *Geographic coverage:* Europe and North America.

Input: regularly scans 50 to 60 journals. English, French, German, Russian, Italian, Serbo-Croatian, Czechoslovakian, and Bulgarian. *Sources (percent):* journal articles (95), secondary sources (5).

Data handling: manual.

Additional services: retrospective retrieval searches, full-size copies, microcopies. Translation services: from Serbo-Croatian into English, French, German, Russian, Italian, Czechoslovakian, Bulgarian, Hungarian and Polish; from English, French, German, Russian, Italian, Czechoslovakian, Bulgarian, Hungarian and Polish into Serbo-Croatian.

30 BIODETERIORATION RESEARCH TITLES B.R.T.

Journal, every 3 months, £18. [$37.80.]; microfiche, every 3 months, £18. [$37.80.]; 1972-

Previously published as: INTERNATIONAL BIODETERIORATION BULLETIN—REFERENCE INDEX SUPPLEMENT (IBBRIS) (1967-71). *Contents cumulate into:* WASTE MATERIALS BIODEGRADATION RESEARCH TITLES.

Published by: Biodeterioration Centre, St. Peter's College, University of Aston, College Road, Saltley, Birmingham B8 3TE, England. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: deterioration of biological materials, preservation of wood.

Output: (1800 cited titles in 1977). Arranged by subject. *Format:* bibliographic citations plus price. Titles in English. *Geographic coverage:* worldwide.

Input: Mostly English.

Indexes: *Subject:* own classification system, annual cumulations (controlled vocabulary, available for examination).

Data handling: computerized and manual.

Additional services: retrospective retrieval searches, full-size copies, research and advisory services, and specialized bibliographies. (SDI will soon be available).

31 BIOLOGICAL ABSTRACTS BA

Journal, 24 issues per year, $1360., $1225. to educational institutions [$1500., $1350. to educational institutions.] (does not include price on the two sets of cumulative indexes per year, which cost: $545., $485 to educational institutions. [$610., $550. to educational institutions.]; magnetic tapes (BAT), contact BIOSIS for price; 1926-

Contents cumulate into: BIOSIS PREVIEWS (60 percent of its content) and BIOLOGICAL ABSTRACTS ON TAPE [BAT] (100 percent). *Contents overlap with:* ABSTRACTS OF ENTOMOLOGY, ABSTRACTS OF MYCOLOGY, ABSTRACTS ON HEALTH EFFECTS OF ENVIRONMENTAL POLLUTANTS (HEEP), and the 14 titles in the BIORESEARCH TODAY series.

Published by: Biosciences Information Service (BIOSIS), 2100 Arch Street, Philadelphia, Pa. 19103, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: all aspects of biological sciences, including forestry.

Output: more than three million abstracts through 1977 (155,012 abstracts in 1977 [2450 abstracts on forestry]). Arranged by subject. *Format:* full bibliographic citations plus abstracts, authors' addresses and ISBN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 8000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles plus government documents and reports (94), monographs (1), conference papers (5).

Indexes: *Author:* each issue (24 per year), with semiannual cumulations. *Subject:* title words in context, preceded or followed, or both, by other keywords not in context, permuted format, each issue (24 per year), with semiannual cumulations (about 19 terms per citation). *Taxonomic:* Generic Index (genus and species); Biosystematic Index (above genus level). *Other:* Concept Index (more than 500 broad subject headings in biology).

Data handling: computerized.

BIOLOGICAL ABSTRACTS/RRM (REPORTS, REVIEWS, MEETINGS)

Journal, monthly, $725., $650 to education institutions [$800, $720 to educational institutions outside U.S.A.]; 1980-

Previously published as: BIORESEARCH TITLES (1965-66); BIORESEARCH INDEX (1967-1979). *Contents cumulate into:* BIOSIS PREVIEWS. *Contents overlap with:* ABSTRACTS OF ENTOMOLOGY, ABSTRACTS OF MYCOLOGY, and ABSTRACTS ON HEALTH EFFECTS OF ENVIRONMENTAL POLLUTANTS (HEEP).

Published by: Biosciences Information Service, 2100 Arch Street, Philadelphia, Pa. 19103, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: biology in general.

Output: more than one million citations through 1977 (125,000 content summaries anticipated for 1980). Arranged by subject categories. *Format:* content summaries (bibliographic citations plus keywords, subject headings, subject concepts, taxonomic descriptors, authors' addresses and ISBN). Titles in English. *Geographic coverage:* worldwide.

Input: books, book chapters, technical reports, annual reports, nomenclature rules, review journals, bibliographies, conference abstracts, symposia papers, workshops and colloquia. Almost all languages included. *Sources (percent):* reports (25), reviews (15), meetings (60).

Indexes: *Author:* monthly. *Subject:* monthly. *Taxonomic:* Generic Index (genus and species), Biosystematic Index (above genus level). *Other:* Concept Index (more than 500 broad subject headings in biology).

Data handling: computerized.

BIORESEARCH TODAY—PESTICIDES

Journal, monthly, $60. [$60.]; 1972-

Contents cumulate into: BIOSIS PREVIEWS, BIOLOGICAL ABSTRACTS and BIOLOGICAL ABSTRACTS ON TAPE.

Published by: Biosciences Information Service (BIOSIS), 2100 Arch Street, Philadelphia, Pa., 19103, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: pesticides.

Output: (about 1800 abstracts in 1977). Arranged by BIOLOGICAL ABSTRACTS reference number. *Format:* full bibliographic citations plus abstracts and authors' addresses. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 8000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles plus government documents and reports (94), monographs (1), conference papers (5).

Data handling: computerized.

34 BIOSIS PREVIEWS

Magnetic tapes, 3 times per month, lease agreement—basic fee is $3750, plus additional usage charges; 1975-

Previously published as: BA PREVIEWS (1969-1975). *Contents overlap with:* BIOLOGICAL ABSTRACTS and BIOLOGICAL ABSTRACTS/RRM (together, these constitute BIOSIS PREVIEWS).

Published by: Biosciences Information Service (BIOSIS), 2100 Arch Street, Philadelphia, Pa. 19103, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: biology in general.

Output: 2,130,000 citations for 1969-1977 (260,148 citations compiled in 1977 [3771 on forestry]). Arranged by numeric system for computer (output is tailored by search strategy). *Format:* full bibliographic citations plus keywords, authors' addresses, CODEN and ISBN. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 8000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles plus government documents and reports (94), monographs (1), conference papers (5).

Indexes: keywords, author names, concept codes and biosystematic (taxonomic) codes are all searchable (about 19 terms per citation).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, standard profiles (28 different profiles).

35 *BOLETIM BIBLIOGRAFICO—CELULOSE NIPO-BRASILEIRA S.A.

Bulletin; price and frequency not given.

Published by: Celulose Nipo-Brasileira S.A., Central de Informacoes Tecnicas, Av. Amazonas 491—10o andar, 30.000—Belo Horizonte, MG, Brazil. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: cellulose and other forest products.

36 BOLETIN BIBLIOGRAFICO—BIBLIOGRAPHICAL BULLETIN, INSTITUTO LATINO-AMERICANO DE INVESTIGACION Y CAPACITACION (EDICION CASTELLANA E INGLESA)

Journal, irregularly, free on request (also included as part of subscription to Boletin Tecnico de IFLAIC); 1976?-

Previously published as: NO. 1: BOLETIN BIBLIOGRAFICO DEL INSTITUTO FORESTAL LATINO-AMERICANO DE INVESTIGACION Y CAPACITACION; NO. 2-35: BOLETIN BIBLIOGRAFICO EDITADO POR EL INSTITUTO FORESTAL LATINO-AMERICANO (1963-1975).

Published by: Director, Instituto Forestal Latino-Americano de Investigacion y Capacitacion, Apartado 36, Merida, Venezuela. (Cables: IFLAIC—Merida, Tel. 074-22709). *Issuing organization:* same as publisher. *Associated libraries:* Biblioteca de la Facultad de Ciencias Forestales (and other libraries), La Universidad de Los Andes, Merida, Venezuela; Biblioteca del Laboratorio Nacional de Productos Forestales, Merida, Venezuela.

Subject coverage: forestry and forest products.

Output: 120,000 citations through 1977 (417 abstracts printed of 7320 citations compiled in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, digests, subject headings, source, price, and authors' addresses. Titles in original language, Spanish, and English. Abstracts in Spanish and about half also in English. *Geographic coverage:* principally Latin America.

Input: regularly scans 170 journals, seven secondary sources. English, Portuguese, French, German, Italian, and Dutch. *Sources (percent):* journal articles (35), monographs (5), government documents and reports (5), conference papers (5), secondary sources (50).

Indexes: *Author:* each issue. *Subject:* each issue. *Taxonomic:* each issue. Cumulative indexes for each 5 years are planned.

Data handling: manual.

Additional services: SDI, retrospective retrieval searches, reference service, full-size copies. Translation services: from Spanish into English, French, German and Dutch, and from English, French, German, and Dutch into Spanish.

37 BOLETIN BIBLIOGRAFICO Y DOCUMENTAL, Escuela Tecnica Superior de Ingenieros de Montes (Bibliographic and Documentation Bulletin, Senior Technical School of Forest Engineers)

Bol. Bib. Doc. ETSIM

Journal, every 3 months, 600 pts. [750 pts., $12.]; 1968-

Published by: Biblioteca, Escuela Tecnica Superior de Ingenieros de Montes, Ciudad Universitaria, Madrid-3, Espana (Rosario Martin-Montalvo, ed.). *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: forestry and forest products.

Output: 11,415 citations through 1977 (569 abstracts, 567 cited titles printed in 1977, 1814 citations compiled in 1977). Arranged by subject, author, and titles of journals scanned. *Format:* full bibliographic citations plus source, ISBN, and UDC. Titles in original language. *Geographic coverage:* principally Spain, with some coverage of Europe, parts of Latin America, Canada, United States, and other countries.

Input: regularly scans 72 journals. List of publications regularly scanned available for examination. Spanish, French, English, Italian, German. *Sources (percent):* journal articles (45), monographs (45), secondary sources (6), other (4).

Indexes: *Subject:* UDC-ODC, every 3 months.

Data handling: manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, library loans.

*BULETIN DE INFORMARE—SERIE: SILV.—IND. LEMNULUI (INFORMATION BULLETIN—SERIES: SILVICULTURE AND WOODWORKING INDUSTRIES)

Bulletin: price and frequency not given.

Published by: Universitatea din Brasov, Biblioteca Centrala, 2200 Brasov, Romania. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: silviculture and woodworking industries.

BULLETIN BIBLIOGRAPHIQUE (BIBLIOGRAPHICAL BULLETIN)

B.B.

Journal, 5 issues per year, 48 FF [53 FF]; 1950-

Published by: Centre Technique du Bois, 10 avenue de Saint Mande, 75012 Paris, France. *Issuing organization:* same as publisher. *Associated library:* Bibliotheque, CTB, 10 avenue de Saint Mande, 75012 Paris, France.

Subject coverage: forest products.

Output: (800 abstracts printed, 850 citations compiled in 1977). Arranged by subject according to CTB's own decimal classification scheme. *Format:* full bibliographic citations plus abstracts and ISSN. Titles in original language and French. Abstracts in French. *Geographic coverage:* worldwide.

Input: regularly scans 200 journals, four secondary sources. List of journals regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (80), monographs (5), government documents and reports (2), conference papers (1), secondary sources (2), other (10).

Data handling: manual.

Additional services: bibliographical searches, full-size copies.

*BULLETIN SIGNALETIQUE 370: BIOLOGIE ET PHYSIOLOGIE VEGETALES

Journal, monthly, contact CNRS for price; magnetic tapes, monthly, contact CNRS for price; 1961-

Contents cumulate into: PASCAL (Programme Applique a la Selection et a la Compilation Automatique de la Literature).

Published by: Centre de Documentation, Centre National de la Recherche Scientifique, 26, rue Boyer, 75971 Paris CEDEX, France. *Issuing organization:* Same as publisher. *Associated library:* same as publisher.

Subject coverage: biology and physiology of plants.

Output: arranged by subject categories. *Format:* full bibliographic citations plus digests, first author's affiliation, and language(s) of item and any summaries. Titles in original language and French. Digests in French. *Geographic coverage:* worldwide.

Input: regularly scans 9000 journals. Almost all languages included.

Indexes: *Author:* monthly, with annual cumulations. *Subject:* KWOC, monthly, with annual cumultions (controlled vocabulary, available for examination). *Geographic:* monthly, with annual cumulations. *Taxonomic:* monthly, with annual cumulations.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches.

CA CONDENSATES

CACon

Magnetic tapes, biweekly, $4000, plus quarterly-use fees and handling charges; 1967-

Contents cumulate into: CHEMICAL ABSTRACTS.

Published by: Chemical Abstracts Service (A Division of the American Chemical Society), P.O. Box 3012, Columbus, Ohio, 43210, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: all fields of chemistry.

Output: 3,131,800 cited titles through 1977 (409,841 cited titles printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus keywords, source, price, authors' addresses, CODEN, and ISSN. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans 12,000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), monographs (11), government documents and reports (4), conference papers (5), patents (10).

Indexes: *Author:* bimonthly. *Subject:* bimonthly.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches.

42 CANADA WATER CWA

Magnetic tapes, monthly, available at a nominal cost for on-line searching in North America through QL Systems Limited (contact WATDOC for further information); 1977-

Previously published as: ENVIRONMENT (1972-77).

Published by: WATDOC (Water Resources Document Reference Centre), Inland Waters Directorate, Fisheries and Environment Canada, Ottawa, Ontario, Canada K1A 0E7. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: water resources and water management in Canada.

Output: 27,700 citations through 1977 (4375 citations in 1977). Arrangement determined by search strategy for terminal display. *Format:* full bibliographic citations plus abstracts, keywords, authors' addresses, CODEN and water research category codes. Titles in English. Abstracts in English. *Geographic coverage:* Canada.

Input: regularly scans 200 journals. List of journals regularly scanned available for examination. English. *Sources (percent):* journal articles (26), monographs (6), government documents and reports (58), conference papers (10).

Indexes: *Subject:* full text retrieval on-line by keywords, descriptors, or any word in the citation or abstract (controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: retrospective retrieval searches, irregular newsletter.

43 CHEMICAL ABSTRACTS CA

Journal, weekly, $4200 [$4200 plus postage]; microfiche[6], weekly, $3150 plus annual license to copy fee; microfilm[6], 12 to 14 per year, $2500 plus annual license to copy fee; 1907-

Published by: Chemical Abstracts Service (A Division of the American Chemical Society), P.O. Box 3012, Columbus, Ohio 43210, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: chemistry.

Output: 7,759,931 citations through 1977 (410,137 abstracts printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, authors' addresses, and CODEN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 12,000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), monographs (11), government documents and reports (4), conference papers (5), patents (10).

Indexes: *Author:* weekly, with semiannual and 5-year cumulations. *Subject:* semiannual and 5-year cumulations (about 11 terms per citation, controlled vocabulary, available for examination). A noncumulated keyword index is published every week. *Other:* molecular formula index, patent index, patent concordance index, index of ring systems.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, Chemical Abstracts Service Source Index (for use in identifying journal titles and libraries holding them).

44 CHEMICAL TITLES CT

Journal, biweekly, $120 [$135.]; magnetic tape, biweekly, $1300, plus quarterly use fees and handling charges; 1961-

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[6] Both the microfiche version (CA Chemissues) and the microfilm version (Chemical Abstracts on Microfilm) start the subscription with a complete backfile from 1907 to the present. Annual price for the updates drops after the first year: microfiche—$2400 plus fee; microfilm—$1750 plus fee. No indexes are included. They may be purchased separately, either in microfilm or printed.

Published by: Chemical Abstracts Service (A Division of the American Chemical Society), P.O. Box 3012, Columbus, Ohio 43210, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: chemistry.

Output: 1,995,219 cited titles through 1977 (152,357 cited titles printed in 1977). Arranged by titles of primary journals scanned. *Format:* full bibliographic citations plus keywords, CODEN, ISSN, and CODEN CAS Issue Identification. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans 700 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (100).

Indexes: *Author:* biweekly, *Subject:* KWIC, biweekly, (about five terms per citation).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, CASSI.

CHEMICAL-BIOLOGICAL ACTIVITIES **CBAC**

Magnetic tape, biweekly, $2900, plus quarterly use charges and handling charge; 1965-

Contents cumulate into: CHEMICAL ABSTRACTS, sections 1 to 5, 62 to 64.

Published by: Chemical Abstracts Service (A Division of the American Chemical Society), P.O. Box 3012, Columbus, Ohio, 43210, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: biochemistry, pharmacology and pharmaceuticals, essential oils and cosmetics, toxicology, and agrochemicals.

Output: 338,813 citations through 1977 (47,430 abstracts printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, authors' addresses, and CODEN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 12,000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), monographs (11), government documents and reports (4), conference papers (5), patents (10).

Indexes: *Author:* biweekly. *Subject:* biweekly (about 11 terms per citation, controlled vocabulary, available for examination. *Other:* molecular formula index, patent index, registry number index.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches.

CIMFORDITASOK KULFOLDI SZAKFOLYOIRATOKBOL **CIMFORDITASOK**

(Title Translations from Foreign Periodical Publications)

Journal, monthly; price not given; 1968-

Published by: Erdeszeti es Faipari Egyetem, Kozponti Konyvtara, Sopron, Pf. 132, Hungary, H-9401. *Issuing organization:* same as publisher.

Subject coverage: forestry and forest products.

Output: (7000 citations compiled, 6566 cited titles printed in 1977). Arranged by titles of primary journals. *Format:* bibliographic citations. Titles in original language and Hungarian. *Geographic coverage:* worldwide.

Input: List of publications regularly scanned available for examination. European languages only. *Sources (percent):* journal articles (100).

Indexes: *Subject:* monthly (controlled vocabulary, available for examination).

Data handling: manual.

Additional services: SDI, full-size copies, library loans.

COMPREHENSIVE DISSERTATION INDEX **CDI**

Magnetic tapes (searchable through BRS, SDC, and Lockheed), monthly, price determined by vendor and size of search; 1973-

Contents overlap with: DISSERTATION ABSTRACTS INTERNATIONAL, MASTERS ABSTRACTS, and AMERICAN DOCTORAL DISSERTATIONS.

Published by: University Microfilms International, 300 N. Zeeb Rd., Ann Arbor, Mich. 48106, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: all academic subjects, including forestry, forest products, and related fields.

Output: 660,000 citations through 1978 (39,000 citations in 1977). Searchable by keywords, authors or schools, and can be limited to certain years. *Format:* full bibliographic citations plus keywords and subject headings. Titles in original language and English. *Geographic coverage:* worldwide.

Input: 99.5 percent English, remainder in other languages. *Sources (percent):* dissertations and theses (100).

Indexes: *Author:* monthly. *Subject:* monthly (about 1.1 terms per citation).

Data handling: computerized.

Additional services: Datrix II, in-house, batch mode search, xerographic, microfilm and microfiche copies of dissertations and theses.

48 CONFERENCE PAPERS INDEX CPI

Journal, monthly, $270. [$270.]; magnetic tapes, monthly, contact Data Courier for price; 1978-

Previously published as: CURRENT PROGRAMS (1973-1977).

Published by: Data Courier, Inc., 620 South Fifth Street, Louisville, Ky. 40202, U.S.A. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: life and physical sciences, medicine, and engineering.

Output: about 500,000 citations through 1977 (116,050 cited titles in 1977). Arranged by subject. *Format:* bibliographic citations plus subject headings, source, price, authors' addresses and World Meetings Registry Number. Titles in original language. *Geographic coverage:* worldwide.

Input: regularly scans papers of about 800 regional, national, and international meetings per year. Mostly English. *Sources (percent):* conference papers (100).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* monthly, with annual cumulations. (Pandex Thesaurus terms are matched with words in papers' titles.)

Data handling: computerized.

Additional services: on-line searching available through DIALOG, ORBIT, BRS and Information Retrieval Service (European Space Agency).

49 CURRENT AWARENESS BULLETIN OF EDITED REFERENCES CABER

Journal, bimonthly, handling charge of £5 for those outside the Forestry Commission; 1971-

Contents overlap with: FORESTRY COMMISSION LIBRARY REVIEW.

Published by: Forestry Commission Library, Alice Holt Lodge, Wrecclesham, Farnham, Surrey, GU10 4LH, England. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: forestry and forest products.

Output: 6720 citations through 1977 (960 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus ODC classification numbers. Titles in original language and English. *Geographic coverage:* temperate regions, particularly Great Britain.

Input: nearly all English, with a little French, German, and Scandinavian. *Sources (percent):* journal articles (30), monographs (50), government documents and reports (5), conference papers (10), other (5).

Indexes: *Subject classification:* Oxford Decimal Classification for forestry.

Data handling: computerized and manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, library loans, (translations for FC Staff).

50 CURRENT CONTENTS(R)/AGRICULTURE, BIOLOGY AND ENVIRONMENTAL SCIENCES CC(R)/AB&ES

Journal, weekly, $150 ($180 for Central and South America; $200 elsewhere); 1973-

Previously published as: CURRENT CONTENTS(R)/ AGRICULTURE, FOOD AND VETERINARY SCIENCES (1969-1972). *Contents cumulate into:* SCIENCE CITATION INDEX(R) and SCISEARCH(R).

Published by: The Institute for Scientific Information, 325 Chestnut Street, Philadelphia, Pa. 19106, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: agriculture, biology, and environmental sciences.

Output: (more than 80,000 citations in 1977). Arranged by titles of primary journals or sources scanned. *Format:* full bibliographic citations plus source, price, authors' addresses, ISSN, ISBN, and LC Card number. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 1000 journals. Almost all languages included. *Sources (percent):* journal articles (70), conference papers (30).

Indexes: *Author:* weekly. *Subject:* weekly (about five terms per citation).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies (original article tear sheet [OATSR] service).

51 CURRENT CONTENTS(R)/LIFE SCIENCES CC(R)/LS

Journal, weekly, $150. ($180 in Central and South America; $200. elsewhere); 1967-

Previously published as: CURRENT CONTENTS(R)/ PHARMACEUTICAL PUBLICATIONS (1957); CURRENT CONTENTS(R)/YOUR WEEKLY GUIDE TO THE CHEMICAL, PHARMACO-MEDICAL AND LIFE SCIENCE (1958-1966). *Contents cumulate into:* SCIENCE CITATION INDEX R) and SCISEARCH(R).

Published by: The Institute for Scientific Information, 325 Chestnut Street, Philadelphia, Pa. 19106, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: biology, medicine, nutrition, and pharmacology.

Output: (220,000 cited titles in 1977). Arranged by subject, titles of the documents, author. *Format:* full bibliographic citations plus source, price, authors' addresses, ISSN, ISBN, and LC Card Number. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 1000 journals. Almost all languages included. *Sources (percent):* journal articles (95), conference papers (5).

Indexes: *Author:* weekly. *Subject:* weekly (about five terms per citation).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies (original article tear-sheet [OATS(R)] service).

"CURRENT LITERATURE" (Journal of Forestry)

Bibliography in journal, monthly, $22. for individuals, $25. for institutions [$25. for individuals, $31. for inst.]; 1945-

Published by: Society of American Foresters, 5400 Grosvenor Lane, Washington, D.C. 20014, U.S.A. (M.P. Kinch, ed.). *Issuing organization:* same as publisher.

Subject coverage: forestry and forest products.

Output: 12,000 citations through 1977 (600 citations compiled, 420 cited titles printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus source and price. Titles in English. *Geographic coverage:* North America, and some other English-speaking countries.

Input: regularly scans 15 journals. English. *Sources (percent):* monographs (10), government documents and reports (80), conference papers (10).

Data handling: manual.

CURRENT PACKAGING ABSTRACTS CPA

Journal, bimonthly, $75. [in N. America $85.]; Jan. 1973-

Previously published as: PACKAGING BULLETIN (Jan. 1969-Jan. 1973).

Published by: Packaging Library, Main Library Bldg., Room 450, University of California, Davis, Calif. 95616, U.S.A. (Carol Cooper, ed.). *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: packaging research and development.

Output: 40,000 citations through 1977 (1201 abstracts, 138 citations printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts and authors' addresses. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 200 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (100).

Data handling: manual.

Additional services: retrospective retrieval searches, full-size copies.

ECOLOGICAL ABSTRACTS

Journal, bimonthly, £23., $46. [$46.]; 1974-

Previously published as: GEOGRAPHICAL ABSTRACTS—PART B: BIOGEOGRAPHY AND CLIMATOLOGY (1966-1971); GEO ABSTRACTS —PART B: BIOGEOGRAPHY AND CLIMATOLOGY (1972-1973).

Published by: Geo Abstracts LTD, University of East Anglia, Norwich NR4 7TJ, England. *Issuing organization:* Geo Abstracts LTD, Old Station House, Trowse, Norwich NR1 2EE, England.

Subject coverage: ecology, including forest ecology.

Output: 18,167 citations through 1977. Arranged by subject. *Format:* full bibliographic citations plus abstracts, ISBN, source and price. (Titles in original language and English). Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 500 journals, 15 secondary sources. List of primary publications regularly scanned published in the index. Almost all languages included. *Sources (percent):* journal articles, monographs, government documents and reports, and conference papers (90), secondary sources (10).

Indexes: *Author:* annual. *Subject:* variation on KWIC, annual (about seven terms per citation). *Geographic:* annual.

Data handling: computerized, mechanical, and manual.

Additional services: retrospective retrieval searches under development.

55 ECOLOGY AND ENVIRONMENT

Magnetic tapes, biweekly, $2500 plus quarterly use charges and handling charge; 1975-

Contents cumulate into: CHEMICAL ABSTRACTS.

Published by: Chemical Abstracts Service (A Division of the American Chemical Society), P.O. Box 3012, Columbus, Ohio 43210, U.S.A. *Issuing organization:* same as publisher.

Subject coverage: environmental sciences as related to chemistry.

Output: 135,144 citations through 1977 (49,825 abstracts printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, authors' addresses, and CODEN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 12,000 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), monographs (11), government documents and reports (4), conference papers (5), patents (10).

Indexes: *Author:* biweekly. *Subject:* biweekly about 11 terms per citation, controlled vocabulary, available for examination. *Other:* molecular formula index, patent index, registry numbers index.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches.

56 ENTOMOLOGY ABSTRACTS

Journal, monthly, £80 [$225.]; 1969/1970-

Contents overlap with: APPLIED ECOLOGY ABSTRACTS.

Published by: Information Retrieval Ltd., 1 Falconberg Court, London W1V 5FG, U.K. *Issuing organization:* same as publisher.

Subject coverage: entomology.

Output: 9300 citations in 1977. Arranged by subject. *Format:* bibliographic citations plus abstracts, source available, price, authors' addresses, ISSN and ISBN. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: Regulary scans 5000 journals, 5 to 10 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (90), monographs (0.5), government documents and reports (1), conference papers (5), secondary sources (0.5), other (3).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* KWIC, monthly, with annual cumulations (about six terms per citation). *Taxonomic:* combined into subject index.

Data handling: computerized and mechanical.

Additional services: a database and allied computer-produced services such as S.D.I., and others will be available in the near future.

57 ENVIRONMENT ABSTRACTS

Journal, monthly, price not given; microforms, price and frequency not given; magnetic tapes, monthly, price not given; 1974-

Previously published as: ENVIRONMENT INFORMATION ACCESS (1970-73). *Contents overlap with:* LAND USE PLANNING ABSTRACTS.

Published by: Environment Information Center (EIC), 292 Madison Ave., 3rd Floor, New York, N.Y. 10017, U.S.A. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: environment and energy.

Output: (6800 abstracts, 7510 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, and source. Titles in original language. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 2500 journals, 350 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (53), monographs (5), government documents and reports (7), conference papers (35).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* KWIC, monthly, with annual cumulations (about eight terms per citation, controlled vocabulary, available for examination). *Geographic:* annual. *Source index:* frequency not given.

Data handling: computerized and manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies.

EPA PUBLICATIONS BIBLIOGRAPHY, QUARTERLY ABSTRACT BULLETIN

Journal, quarterly, $50 in North America (others contact NTIS); 1970-

Contents cumulate into: NTIS BIBLIOGRAPHIC DATA FILE; GOVERNMENT REPORTS ANNOUNCEMENTS and INDEX. [Note: There is a retrospective cumulation EPA CUMULATIVE BIBLIOGRAPHY, 1970-1976.]

Published by: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, Va. 22161, U.S.A. *Sponsoring organization:* Library Systems Branch, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, D.C. 20460, U.S.A. *Associated library:* same as publisher.

Subject coverage: environmental protection and management.

Output: (2100 abstracts in 1977). Arranged by NTIS accession number. *Format:* full bibliographic citations plus abstracts, descriptors, identifiers, source, price, geographic descriptors, NTIS order number, and sponsoring organization. Titles in English. Abstracts in English. *Geographic coverage:* principally United States.

Input: Government-sponsored research reports that are publicly available and generated by EPA authors or funding. English. *Sources (percent):* government documents and reports (100). (Some of these are in the form of dissertations, patents, conference papers, or other.)

Indexes: *Author:* quarterly, with an annual cumulation in the fourth quarterly issue. *Subject:* quarterly, with an annual cumulation in the fourth quarterly issue (about 10 terms per citation, controlled vocabulary, available for examination). *Title:* quarterly, with an annual cumulation in the fourth quarterly issue. *Corporate author:* quarterly, with an annual cumulation in the fourth quarterly issue. *Sponsoring EPA office:* quarterly, with an annual cumulation in the 4th quarterly issue. *Contract number:* quarterly, with an annual cumulation in the fourth quarterly issue. *Accession or report number:* quarterly, with an annual cumulation in the fourth quarterly issue.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, print products (such as special bibliographies), full-size copies, microcopies.

EXCERPTA MEDICA—SECTION 46 (ENVIRONMENTAL HEALTH AND POLLUTION CONTROL) **EMBASE section 46**

Journal, 20 times per year, Dfl. 536; magnetic tapes, weekly, price negotiable; 1971-

Published by: Excerpta Medica, P.O. Box 1126, 1000 BC Amsterdam, The Netherlands. *Issuing organization:* same as publisher.

Subject coverage: environmental health and pollution.

Output: 38,000 citations through 1977 (5400 citations compiled; 4647 abstracts, 5278 cited titles printed in 1977). Arranged by subject (in journal) and date of citation input (on magnetic tape). *Format:* full bibliographic citations plus abstracts, keywords, subject headings, price, authors' addresses, CODEN, ISBN, codes for languages and for country of authors. Titles in English, and in original language if French, German, Italian, Portuguese or Spanish. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 10,000 journals. Partial list of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (90), monographs (3), government documents and reports (3), conference papers (4).

Indexes: *Author:* every 2½ weeks, with semiannual cumulations. *Subject:* modified rotated chain index (key words followed by all other key words), every 2½ weeks, with semiannual cumulations (about six terms per citation, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies, translations from any language into any language.

FAO DOCUMENTATION CURRENT BIBLIOGRAPHY **FAO DOC**

Journal, monthly, free on request; microfiche, annual, $10. [$10.]; 1967-

Contents cumulate into: AGRIS.

Published by: Food and Agriculture Organization of the United Nations, Via Delle Terme di Caracalla, Rome, Italy. *Issuing organization:* same as publisher. *Associated library:* David Lubin Memorial Library, Food and Agriculture Organization, Via Delle Terme di Caracalla, Rome, Italy.

Subject coverage: food and agriculture.

Output: 54,117 citations through 1977 (3223 abstracts in 1977). Arranged by Technical Divisions of FAO originating the documents. *Format:* full bibliographic citations plus abstracts, keywords, source, and ISBN. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 15 journals. English, French and Spanish. *Sources (percent):* journal articles (5), monographs (10), government documents and reports (25), conference papers (60). (Publications produced by FAO.)

Indexes: *Author:* monthly, cumulated each successive year up to 4 years. *Subject:* KWOC, monthly, cumulated each successive year up to 4 years (about eight terms per citation, controlled vocabulary, available for examination). *Geographic:* published monthly and incorporated in Subject Index. *Other indexes:* by originating divisions, by FAO Field Project codes.

Data handling: computerized.

Additional services: retrospective retrieval searches, full-size copies, microcopies.

61 FERTILIZER ABSTRACTS **Fert. Abstr.**

Journal, monthly, $30. [$45.]; 1968-

Published by: Tennessee Valley Authority, Fertilizer Abstracts Service, National Fertilizer Development Center, A218, Muscle Shoals, Ala. 35660 U.S.A. *Issuing organization:* same as publisher. *Associated library:* Tennessee Valley Authority, Technical Library, National Fertilizer Development Center, Muscle Shoals, Ala. 35660 U.S.A.

Subject coverage: fertilizers, including forest fertilization.

Output: 22,000 citations through 1977 (2841 abstracts, 300 citations printed in 1977). Arranged by subject. *Format:* full bibliographic citations, plus price. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 400 journals, 20 secondary sources. List of publications regularly scanned available for examination. English. *Sources (percent):* journal articles (60), monographs (5), government documents and reports (1), conference papers (6), patents (5), secondary sources (20), other (3).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* monthly, with annual cumulations (about two terms per citation).

Data handling: manual.

Additional services: assistance in locating original copies.

62 FISH AND WILDLIFE REFERENCE SERVICE NEWSLETTER **FWRS**

Newsletter, quarterly, free; 1974-

Previously published as: NEWSLETTER, LIBRARY REFERENCE SERVICE (1967-1974). *Contents cumulate into:* INDEXES OF STATE RESEARCH database.

Published by: Denver Public Library, 3840 York Street, Unit I, Denver, Colo. 80205, U.S.A. *Issuing organization:* Fish and Wildlife Reference Service, Denver Public Library, 3840 York Street, Unit I, Denver, Colo. 80205 U.S.A. *Associated library:* same as issuing organization.

Subject coverage: sports fisheries and game management, and endangered species.

Output: 12,500 citations in computer database, plus another 30,000 citations on file through 1977 (60 abstracts, 180 cited titles printed, 800 citations compiled in 1977). Arranged by subject category. *Format:* full bibliographic citations plus abstracts (for 25 percent of items). Computer database also has subject and geographic descriptors. Titles in English. Abstracts in English. *Geographic coverage:* U.S.A.

Input: regularly inputs publications of regional U.S. Fish and Wildlife Service offices, masters theses and doctoral dissertations funded by cooperative fish and wildlife units, some State Fish and Game Departments' reports, and endangered species recovery plans. English. *Sources (percent):* monographs, dissertations, theses (10), government documents and reports (90). (About 10 terms per citation in database, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: retrospective retrieval searches, Fish and Wildlife Thesaurus, referral, indexes of state research[7], full-size copies, microcopies.

63 FOREST PRODUCTS ABSTRACTS **FPA**

Journal, monthly, £60; microforms, monthly, £60. card service, monthly, price not given; magnetic tapes, monthly, contact CAB for pricing schedule; 1978-

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[7] FWRS also has stored in its computer database an INDEX OF STATE RESEARCH for each state, with output arranged in four ways. The Index is available free to cooperators (those funded under the Federal Aid to Fish and Wildlife Restoration programs and the Anadromous Fish Conservation program) and for $10 per computer print-out section (one for fish and one for wildlife) per state for other clients. It is also available in microfiche to other clients for $5 per section. Each section comes with four differently-arranged listings for the citations: by FWRS accession number (MIN number), by authors, by project numbers, and by weighted-subject terms cross-referenced to the accession number listing.

Previously published as: part of FORESTRY ABSTRACTS (1939-1977). *Contents cumulate into:* CAB ABSTRACTS.

Published by: Commonwealth Agricultural Bureaux (CAB), Farnham Royal, Slough, SL2 3BN, U.K. *Issuing organization:* Commonwealth Forestry Bureau, South Parks Road, Oxford, OX1 3RD, U.K. *Associated library:* Commonwealth Forestry Bureau, South Parks Road, Oxford, OX1 3RD, U.K.

Subject coverage: forest products.

Output: 2250 abstracts, 250 cited titles in 1978. Arranged by subject. *Format:* full bibliographic citations plus abstracts, source, price, authors' addresses, ISSN, and ISBN. Titles in original language and English, occasionally French. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 1000 journals, 20 secondary sources. List of publications regularly scanned available for examination. Almost all languages are included.

Indexes: *Author:* monthly, with annual cumulations. *Subject:* annual (about five terms per citation). *Geographical:* included in subject index. *Taxonomic:* monthly, with annual cumulations.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies.

FORESTRY ABSTRACTS FA

Journal, monthly, special rate for subscribers in CAB member countries (£100. in nonmember countries); magnetic tapes, monthly, price not given; Card Title Service, monthly, price not given; 1939-

Contents overlap with: CARD TITLE SERVICE, C.F.B. *Contents cumulate into: CAB ABSTRACTS.*

Published by: Commonwealth Agricultural Bureaux, Farnham Royal, Slough, SL2 3BN, U.K. *Issuing organization:* Commonwealth Forestry Bureau, South Parks Road, Oxford OX1 3RD, U.K.

Subject coverage: forestry and forest products.

Output: 190,000 citations through 1977 (7004 citations printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, source and price, ISSN, and ISBN. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 1200 journals, 20 secondary sources. List of publications regularly scanned available for examination. Almost all languages included.

Indexes: *Author:* monthly, with annual cumulations. *Subject:* annual (four or five terms per citation, controlled vocabulary, available for examination.) *Taxonomic:* monthly, with annual cumulations.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, annotated bibliographies, full-size copies.

FORESTRY COMMISSION LIBRARY REVIEW

Journal, every 4 months, free; 1965-

Contents cumulate into: CABER: Current Awareness Bulletin of Edited References.

Published by: Alice Holt Lodge, Forest Research Station, Wrecclesham, Farhnam, Surrey GU10 4LH, England. *Issuing organization:* same as publisher. *Associated library:* The Library, Alice Holt Lodge, Forest Research Station, Wrecclesham, Farnham, Surrey GU10 4LH, England.

Subject coverage: forestry and some forest products.

Output: 320 citations printed of 960 citations compiled in 1977. Arranged by document type. *Format:* full bibliographic citation plus O.D.C. Titles in original language and English. *Geographic coverage:* temperate region, particularly Great Britain. English, with some exceptions. *Sources (percent):* journal articles (15), monographs (60), government documents and reports (10), conference papers (10), other (5).

Data handling: computerized and manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, library loans.

FORESTRY THESES ACCEPTED BY COLLEGES AND UNIVERSITIES IN THE UNITED STATES

Booklet, every 3 years[8], $3.00; 1953-

Published by: Oregon State University Press, 101 Waldo, Corvallis, Oreg. 97331 U.S.A. (edited by M.P. Kinch, Kerr Library, O.S.U.). *Issuing organization:* same as publisher.

Subject coverage: forestry and forest products.

Output: 8000 citations through 1977. Arranged by university or college, then by author. *Format:* full bibliographic citations plus keywords. Titles in English. *Geographic coverage:* U.S.A.

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[8] Previous editions available in cumulative form are: 1900-1952 ($1.50); 1953-1955 ($1.50); 1956-1966 ($3.00); 1966-1973 ($3.00); 1973-1976 ($3.00).

Input: *Sources (percent):* dissertations, theses (100). English.
Indexes: *Subject:* published every issue (about two items per citation).
Data handling: manual.

67 FORSKNINGS—OCH FOSOKSMEDDELANDEN FRAN INSTITUTIONER PA JORDBRUKETS, TRADGARDSODLINGENS, SKOGENS M. FL. OMRADEN (LIST OF PUBLICATIONS OF SWEDISH RESEARCH INSTITUTIONS IN AGRICULTURE, HORTICULTURE, FORESTRY, AND RELATED FIELDS)

FORSKNING OCH FORSOK

Offprint from journal[9], annual, 10Kr.; 1962-

Previously published as: FORSKNINGS—OCH FORSOKSMEDDELANDEN. OFFENTLIGGJORDA RESULTAT M. M. FRAN INSTITUTIONER PA JORDBRUKETS, TRADGARDSODLINGENS, SKOGENS M. FL. OMRADEN (1956-1961).

Published by: Kungl. Skogs—och Lantbruksakademien, The Royal Swedish Academy of Agriculture and Forestry, Box 6806, S-113 86, Stockholm, Sweden. *Issuing organization:* Kungl. Skogs—och Lantbruksakademien, Biblioteket (The Royal Swedish Academy of Agriculture and Forestry, Library). *Associated library:* same as the issuing organization.

Subject coverage: forestry and forest products.

Output: 516 cited titles in 1977. Arranged by author. *Format:* bibliographic citations plus source available. Titles in original language and occasionally English, German, or French. *Geographic coverage:* Sweden.

Input: citations dervied from the primary literature; Swedish, some English, German, and French.

Indexes: *Author:* annual. Journal abbreviation index (frequently not given).

Additional services: full-size copies, library loans, remittance to other libraries if required titles are not available here.

68 GEO ABSTRACTS—PART A: LANDFORMS AND THE QUARTERNARY

Journal, bimonthly, £8.80, $17.60 [$17.60]; 1972-

Previously published as: GEOGRAPHICAL ABSTRACTS —PART A: GEOMORPHOLOGY (1966-1971); GEOMORPHOLOGICAL ABSTRACTS (1960-1965).

Published by: Geo Abstracts LTD, University of East Anglia, Norwich NR4 7TJ, England. *Issuing organization*: Geo Abstracts LTD, Old Station House, Trowse, Norwich NR 1 2EE, England.

Subject coverage: geomorphology, including forest ecology.

Output: 29,231 citations through 1977 (2499 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, source, price, and ISBN. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 725 journals, 15 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles, monographs, government documents and reports, and conference papers (80), secondary sources (20).

Indexes: *Author:* annual, with cumulations every 6 years. *Subject:* conventional alphabetical, variation on KWIC, annual, with cumulations every 6 years (about seven terms per citation). *Geographic:* annual.

Data handling: computerized, mechanical, manual.

Additional services: retrospective retrieval searches are being developed.

69 GEO ABSTRACTS—PART B: CLIMATOLOGY AND HYDROLOGY

Journal, £8.80, $17.60 [$17.60]; 1972-

Previously published as: GEOGRAPHICAL ABSTRACTS, PART B: BIOGEOGRAPHY AND CLIMATOLOGY (1966-1971).

Published by: Geo Abstracts LTD, University of East Anglia, Norwich NR4 7TJ, England. *Issuing organization:* Geo Abstracts LTD, Old Station House, Trowse, Norwich NR1 2EE, England.

Subject coverage: climatology and hydrology.

Output: 28,160 citations through 1977 (3020 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, source, price, and ISBN. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

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[9] Offprint from issue 4/5 each year. Also, in each number of the Journal of the Royal Swedish Academy of Agriculture and Forestry, *Kungliga Skogs— och Lantbruksakademiens tidskrift*, a series of important articles in foreign periodicals (forestry) included, "Viktigare skogliga uppsatser i nyutkomna utlandska tidskrifter".

Input: regularly scans 725 journals, 15 secondary sources. Almost all languages included. *Sources (percent):* journal articles, monographs, government documents and reports, and conference papers (70), secondary sources (30).

Indexes: *Author:* annual, with cumulations every 6 years. *Subject:* conventional alphabetical, variation on KWIC, annual, with cumulations every 6 years (about seven terms per citation). *Geographic:* annual.

Data handling: computerized, mechanical, manual.

Additional services: retrospective retrieval searches are being developed.

GEO ABSTRACTS—PART C: ECONOMIC GEOGRAPHY

Journal, bimonthly, £8.80, $17.60 [$17.60]; 1972-

Previously published as: GEOGRAPHICAL ABSTRACTS— PART C: ECONOMIC GEOGRAPHY (1966-1971).

Published by: Geo Abstracts LTD, University of East Anglia, Norwich NR4 7TJ, England. *Issuing organization:* Geo Abstracts LTD, Old Station House, Trowse, Norwich NR1 2EE, England.

Subject coverage: economic geography.

Output: 26,187 citations through 1977 (3205 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, source, price, and ISBN. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 730 journals, 15 secondary sources. List of the publications available. Almost all languages included. *Sources (percent):* journal articles, monographs, government documents and reports, and conference papers (75), secondary sources (25).

Indexes: *Author:* annual, with cumulations every 6 years. *Subject:* variation on KWIC, annual, with cumulations every 6 years (about seven terms per citation). *Geographic:* annual.

Data handling: computerized, mechanical, manual.

Additional services: retrospective retrieval searches are being developed.

GEO ABSTRACTS—PART D: SOCIAL AND HISTORICAL GEOGRAPHY

Journal, bimonthly, £8.80, $17.60 [$17.60]; 1972-

Previously published as: GEOGRAPHICAL ABSTRACTS—PART D: SOCIAL GEOGRAPHY (1966-1967); GEOGRAPHICAL ABSRACTS—PART D: SOCIAL GEOGRAPHY AND CARTOGRAPHY (1968-1971).

Published by: Geo Abstracts LTD, University of East Anglia, Norwich NR4 7TJ, England. *Issuing organization:* Geo Abstracts LTD, Old Station House, Trowse, Norwich NR1 2EE, England.

Subject coverage: social geography, historical geography, including some forestry.

Output: 24,758 citations through 1977 (2783 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, ISBN, source, and price. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 730 journals, 15 secondary sources. List of primary publications regularly scanned published in the index. Almost all languages included. *Sources (percent):* journal articles, monographs, government documents and reports, and conference papers (75), secondary sources (25).

Indexes: *Author:* annual, with cumulations every 6 years. *Subject:* variation on KWIC, annual, with cumulations every 6 years (about seven terms per citation). *Geographic:* annual.

Data handling: computerized, mechanical, and manual.

Additional services: retrospective retrieval searches are being developed.

GEO ABSTRACTS—PART E: SEDIMENTOLOGY

Journal, bimonthly, £8.80, $17.60 [$17.60]; 1972-

Published by: Geo Abstracts LTD, University of East Anglia, Norwich NR4 7TJ, England. *Issuing organization:* Geo Abstracts LTD, Old Station House, Trowse, Norwich NR1 2EE, England.

Subject coverage: sedimentology, including forest ecology.

Output: 14,235 citations through 1977 (2535 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, ISBN, source, and price. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 725 journals, 15 secondary sources. List of primary publications regularly scanned published in the index. Almost all languages included. *Sources (percent):* journal articles, monographs, government documents and reports, and conference papers (75), secondary sources (25).

Indexes: *Author:* annual. *Subject:* variation on KWIC, annual (about seven terms per citation). *Geographic:* annual.

Data handling: computerized, mechanical, and manual.

Additional services: retrospective retrieval searches are being developed.

73 GEO ABSTRACTS—PART F: REGIONAL AND COMMUNITY PLANNING

Monthly, £8.80, $17.60 [$17.60]; 1972-

Published by: Geo Abstracts LTD, University of East Anglia, Norwich NR4 7TJ, England. *Issuing organization:* Geo Abstracts LTD, Old Station House, Trowse, Norwich NR1 2EE, England.

Subject coverage: regional planning, community planning, land use, including recreation, range, forest, and game management.

Output: 15,349 citations through 1977 (3089 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, ISBN, source, and price. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 730 journals, 15 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles, monographs, government documents and reports, and conference papers (70), secondary sources (30).

Indexes: *Author:* annual. *Subject:* variation on KWIC, annual (about seven terms per citation). *Geographic:* annual.

Data handling: computerized, mechanical, and manual.

Additional services: retrospective retrieval searches are being developed.

74 GEO ABSTRACTS—PART G: REMOTE SENSING AND CARTOGRAPHY

Journal, bimonthly, £8.80, $17.60 [$17.60]; 1974-

Published by: Geo Abstracts LTD, University of East Anglia, Norwich NR4 7TJ, England. *Issuing organization:* Geo Abstracts LTD, Old Station House, Trowse, Norwich NR1 2EE, England.

Subject coverage: remote sensing and cartography, including forestry.

Output: 9217 citations through 1977 (2346 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, ISBN, source, and price. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 725 journals, 16 secondary sources. List of primary publications regularly scanned published in the index. Almost all languages included. *Sources (percent):* journal articles, monographs, government documents and reports, and conference papers (60), secondary sources (40).

Indexes: *Author:* annual. *Subject:* variation on KWIC, annual (about seven terms per citation). *Geographic:* annual.

Data handling: computerized, mechanical, and manual.

Additional services: retrospective retrieval searches are being developed.

75 GOVERNMENT REPORTS ANNOUNCEMENTS & INDEX GRA&I

Journal, biweekly, $245 in North America (For distribution in other countries, contact NTIS); 1971-

Previously published as: U.S. GOVERNMENT RESEARCH AND DEVELOPMENT REPORTS (1965-1971); U.S. GOVERNMENT RESEARCH REPORTS (1944?-1964). *Contents cumulate into:* NTIS BIBLIOGRAPHIC DATA FILE. *Contents overlap with:* NATURAL RESOURCES and EARTH SCIENCES and 25 other abstract newsletters derived from the NTIS Bibliographic Data File; EPA PUBLICATIONS BIBLIOGRAPHY.

Published by: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Va. 22161 U.S.A. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: science, technology, medicine, and behavioral and social sciences.

Output: 65,000 abstracts in 1977. Arranged by subject categories (COSATI). *Format:* full bibliographic citations plus abstracts, keywords, subject category codes, source, price, geographic descriptors, GRA citation cross-reference, NTIS order number, and sponsoring organization(s). Titles in English. Abstracts in English. *Geographic coverage:* worldwide on many subjects, but primarily U.S.A.

Input: regularly abstracts government-sponsored research reports available to public. English. *Sources (percent):* government documents and reports, some of which are in the form of dissertations, patents, conference papers, and other (100).

Indexes: *Author:* biweekly, with annual cumulations. *Subject:* biweekly, with annual cumulations (about 10 terms per citation, controlled vocabulary, available for examination). *Contract Number and Report-Accession Number:* biweekly, with annual cumulations.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, print products (such as special bibliographies), full-size copies, microcopies.

HERBAGE ABSTRACTS

Journal, monthly, £79.00; microform, monthly, £79.00; magnetic tapes, monthly, price not given; 1931-

Contents cumulate into: CAB ABSTRACTS.

Published by: Commonwealth Agricultural Bureau, Farnham House, Farnham Royal, Slough SL2 3BN, U.K. *Issuing organization:* Commonwealth Bureau of Pastures and Field Crops, Hurley, Maidenhead, Berks. SL6 5LR, U.K.

Subject coverage: rangelands, pastures, and herbage plant ecology.

Output: 100,000 citations through 1977 (4261 abstracts, 200 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, price, authors' addresses, ISBN, and language of text. Titles in original language and English for all languages using Latin, Cyrillic, or Greek scripts. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 1400 journals, 10 secondary sources. List of publications regularly scanned available for examination. Almost all languages included.

Indexes: *Author:* monthly, with annual cumulations. *Subject:* monthly, with annual cumulations (about four terms per citation).

Data handling: computerized.

Additional services: retrospective retrieval searches, full-size copies.

INDEX TO SCIENTIFIC REVIEWS (TM) ISR(TM)

Serial, semiannual, $250; 1974-

Contents cumulate into: SCIENCE CITATION INDEX (R) and SCISearch (R).

Published by: The Institute for Scientific Information, 325 Chestnut Street, Philadelphia, Pa. 19106 U.S.A. *Issuing organization:* same as publisher.

Subject coverage: science, medicine, agriculture, technology, and behavioral sciences.

Output: 25,000 source citations printed in 1977; 500,000 citations compiled in total SCISearch database in 1977. Arranged in separate sections by subject, titles of source documents, authors-editors of source items, cited authors, corporate authors, and patent numbers. *Format:* bibliographic citations plus authors' addresses. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 3300 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (82), monographic series (18).

Indexes: *Author:* every 6 months, with annual cumulations. *Subject:* permuted title words, every 6 months, with annual cumulations (about 8 terms per citation, includes indexing of author's references or citations). *Geographic:* every 6 months. *Citation Index:* designed to use author's references or footnotes, arranged alphabetically according to cited author followed by notation of the cited work.

Data handling: computerized.

Additional services: retrospective retrieval searches, full-size copies (original article tear sheets [OATS(R)] service).

*INDICE AGRICOLA DE AMERICA LATINA Y EL CARIBE (AGRICULTURAL INDEX OF LATIN AMERICA AND THE CARIBBEAN)

Journal, quarterly, price not given; 1975-

Previously published as: BIBLIOGRAFIA AGRICOLA LATINOAMERICANA Y DEL CARIBE (1966-1974). *Contents cumulate into:* AGRINDEX and ALERTA AL DIA series for several subjects, including ALERTA AL DIA—DASONOMIA.

Published by: Centro Interamericano de Documentacion e Informacion Agricola, Instituto Interamericano de Ciencias Agricolas—OEA, San Jose, Costa Rica. *Issuing organization:* same as publisher, which is the coordinating center for AGRINTER (Inter-American Information System for the Agricultural Sciences). *Associated libraries:* same as publisher, along with the national coordinating center libraries for the other 17 member countries, listed in each issue.

Subject coverage: agriculture.

Output: 9000 cited titles in 1976, 208 under forestry and forest products. Arranged by subject categories. *Format:* full bibliographic citations plus authors' affiliations, library locations, and keywords for some citations. Titles in original language. *Geographic coverage:* South America, Central America, Mexico, and the Caribbean.

Input: agricultural literature published in South America, Central America, Mexico, and the Caribbean. Mostly Spanish and Portuguese, with some English.

Indexes: *Author:* quarterly. *Subject:* KWIC, quarterly.

Data handling: computerized.

79 INFORMACNI ZPRAVODAJ VSZ Brno (INFORMATION BULLETIN, UNIV. OF AGRICULTURE, Brno) **IZ**

Journal, quarterly, available on exchange; 1977-

Previously published as: KNIZNI A DOKUMENTACNI (1967-1976?).

Published by: Ustav vedeckych informaci Vysoke skokly zemedelske v Brno (Department of Scientific Information, University of Agriculture, Brno), Czechoslovakia. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: agriculture, including forestry.

Output: 165 abstracts, 640 citations in 1977 (110 plus 192 in forestry). Arranged by author within subject categories. *Format:* full bibliographic citations, plus keywords (for reports and theses), abstracts (for reports and theses), and subject headings. Titles in original language, Russian, and English. Abstracts in Czech (Slovak), Russian and English. *Geographic coverage:* Czechoslovakia.

Input: List of publications regularly scanned available for examination. Czech, Slovak. *Sources (percent):* journal articles (40), monographs (15), conference papers (5), reports, bibliographies, and translations (40).

Indexes: *Author:* annual. *Subject:* KWIC, annual (about four terms per citation).

Data handling: manual.

Additional services: retrospective retrieval searches, full-size copies, microcopies, library loans. Translation services from English, Russian and German into Czech (Slovak); from Czech (Slovak) into English, Russian, and German.

80 IPEF—BIBLIOTECA

Journal, monthly, price not given; 1975?-

Previously published as: BIBLIOGRAFIA MENSAL IPEF (1973-1974).

Published by: Instituto de Pesquisos e Estudos Florestais (IPEF), Biblioteca, Caixa Postal 9, 13,400—Piracicaba, SP, Brazil. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: forestry and forest products.

Output: 10,000 cited titles through 1977 (1729 cited titles printed, of 2300 citations compiled in 1977). Arranged by subject and then author within document type (books, journals, and other). *Format:* full bibliographic citations plus keywords. Titles in original language. *Geographic coverage:* worldwide.

Input: regularly scans 390 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (50), monographs (30), government documents and reports (2), conference papers (10), secondary sources (5), other (3).

Indexes: *Subject:* monthly (about three terms per citation).

Data handling: manual.

Additional services: SDI, full-size copies.

81 LAND USE PLANNING ABSTRACTS **LUPA**

Book, annual $95 ($110); 1971-1973-

Previously published as: part of ENVIRONMENT INFORMATION ACCESS. *Contents cumulate into:* ENVIRONMENT ABSTRACTS.

Published by: Environment Information Center (EIC), 292 Madison Ave., 3rd Floor, New York, N.Y. 10017 U.S.A. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: land use planning.

Output: 5000 citations through 1977 (1700 abstracts plus bibliographic essays, statistical overviews, list of pending and recently enacted legislation, and list of recently published books in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, and source. Titles in original language. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 2500 journals, 350 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (50), monographs (5), government documents and reports (10), conference papers (35).

Indexes: *Author:* annual. *Subject:* annual (about eight terms per citation, controlled vocabulary, available for examination). *Geographic:* annual. *Other:* Standard Industrial Classification Code, annual.

Data handling: computerized and manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies.

82 LIBRARY ACCESSIONS—WESTERN FOREST PRODUCTS LABORATORY, FORINTEK CANADA CORP.

Monthly accession list, available on exchange; 1979-

Previously published as: LIBRARY ACCESSIONS—WESTERN FOREST PRODUCTS LABORATORY, ENVIRONMENT CANADA (1975-1979).

Published by: Library, Forintek Canada Corp., Western Forest Products Laboratory, 6620 N.W. Marine Drive, Vancouver, B.C., Canada. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: forest products.

Output: 1800 cited titles in 1977. Arranged by author within document-type groupings. *Format:* full bibliographic citations plus ISBN. Titles in original language and English. *Geographic coverage:* primarily western North America, especially Canada.

Input: mostly English, some German. *Sources (percent):* journal articles (10), monographs (20), government documents and reports (60), conference papers (5), patents (5).

Data handling: manual.

MELDETJENESTEN, LANDBRUKS-DEPARTEMENTETS OPPLYSNINGSTJENESTE (REPORTING SERVICE, MINISTRY OF AGRICULTURE INFORMATION SERVICE)

Perforated sheets, monthly, Nkr. 30,-, $5.50 (Nkr. 30,-, $5.50) [this price includes Meldetjenesten on forestry also (38 in 1979)—see citation below]; 1956-

Published by: Landbruksdepartementets opplysningstjeneste, Moerveien 12, N-1430 AS, Norway. *Issuing organization:* same as publisher.

Subject coverage: agriculture.

Output: 120 abstracts in 1977. Arranged by subject. *Format:* full bibliographic citations plus abstracts and price. Titles in original language and Norwegian, Swedish, or Danish. Abstracts in Norwegian, Swedish, or Danish. *Geographic coverage:* primarily northern Europe.

Input: Norwegian, Swedish, Danish, English, German.

Indexes: None. Letter and figure subject codes on each perforated sheet so that subscriber can file each by subject in looseleaf binder.

Data handling: manual.

MELDETJENESTEN, DET NORSKE SKOGSELSKAP (REPORTING SERVICE, NORWEGIAN FOREST SOCIETY)

Perforated sheets, monthly, Nkr. 30,-, $5.50 (Nkr. 30,-, $5.50) [this price includes Meldetjenesten on agriculture also (120 in 1977)—see citation above]; 1956-

Published by: Landbruksdepartementets opplysningstjeneste, Moerveien 12, N-1430 AS, Norway. *Issuing organization:* same as publisher.

Subject coverage: forestry and forest products.

Output: 38 abstracts in 1977. Arranged by subject. *Format:* full bibliographic citations plus abstracts and price. Titles in original language and Norwegian, Swedish, or Danish. Abstracts in Norwegian, Swedish, or Danish. *Geographic coverage:* primarily Northern Europe.

Input: Norwegian, Swedish, Danish, English, German.

Indexes: None. Letter and figure subject codes on each perforated sheet so that subscriber can file by subject.

Data handling: manual.

METEOROLOGICAL AND GEOASTROPHYSICAL ABSTRACTS MGA

Journal, monthly, $400 ($408.)—special prices for public libraries and educational organizations; magnetic tapes, monthly, price subject to negotiation; 1960-

Previously published as: METEOROLOGICAL ABSTRACTS AND BIBLIOGRAPHY (1950-59) *Contents cumulate into:* The MGA computer-readable database. 1976-1978 corresponds exactly with the printed MGA (1976-1978).

Published by: American Meteorological Society, 45 Beacon Street, Boston, Mass. 02108 U.S.A. *Issuing organization:* same as publisher.

Subject coverage: meteorology and geoastrophysics.

Output: 207,000 citations through 1977 (7200 abstracts in 1977). Arranged by subject (UDC classification). *Format:* full bibliographic citations plus abstracts, subject headings, library sources, and UDC Classification Number. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 250 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (80), monographs (10), government documents and reports (5), conference papers (5).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* monthly, with annual cumulations (about four terms per citation). *Geographic:* monthly, with annual cumulations.

Data handling: computerized and manual.

Additional services: special bibliographies.

86 MONTHLY ACCESSIONS LIST, (U.K.) NATIONAL METEOROLOGICAL LIBRARY

Journal, monthly, available on exchange; January, 1975-

Previously published as: MONTHLY BIBLIOGRAPHY (1919-1974).

Published by: National Meteorological Library, Meteorological Office, London Road, Bracknell, Berks., RG12 2SZ, England. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: meteorology.

Output: 500,000 citations through 1977 (9000 cited titles in 1977). Arranged by UDC. *Format:* full bibliographic citations plus source, price, and UDC. Titles of Romance and Germanic language items in original and English; titles in languages with non-Roman script in English translations only. *Geographic coverage:* worldwide.

Input: regularly scans 300 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (40), monographs (25), government documents and reports (15), conference papers (15), other (5).

Indexes: *Subject:* UDC, monthly (two or three terms per citation).

Data handling: computerized and manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, library loans.

87 MUSZAKI LAPSZEMLE. FAIPAR. PAPIR— ES NYOMDAIPAR (TECHNICAL ABSTRACTS. WOODWORKING INDUSTRY. PAPER AND PRINTING INDUSTRY)

Journal, monthly, Ft 540., $21 ($21); 1948-

Published by: Orszagos Muszaki Konvytar es Dokumentacios Kozpont, (Hungarian Central Technical Library and Documentation Centre), H-1428 Budapest, P.O.B. 12. - Reviczky u. 6, Hungary. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: woodworking, paper, and printing industries.

Output: 112,600 citations through 1977 (4521 abstracts, 858 cited titles printed of 5379 citations compiled in 1977). Arranged by broad subject fields (items indexed by UDC). *Format:* full bibliographic citations plus abstracts. Titles in original language and Hungarian. Abstracts in Hungarian. *Geographic coverage:* worldwide.

Input: regularly scans 76 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (88), monographs (1), conference papers (8), patents (1), other (2).

Indexes: *Subject:* annual (about two terms per citation).

Data handling: manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies, library loans, translations of original documents.

88 NATIONAL AGRICULTURE LIBRARY CATALOG

Book catalog, monthly, $100; 1966-

Previously published as: DICTIONARY CATALOG OF THE AGRICULTURAL LIBRARY (1862-1965). *Contents cumulate into:* AGRICOLA.

Published by: Rowman and Littlefield, The Library Division of Littlefield, Adams and Company, 81 Adams Drive, Totowa, N.J. 07511 U.S.A. *Issuing organization:* U.S. Department of Agriculture, Science and Education Administration, Technical Information Systems, Resource Development Division, National Agriculture Library Bldg., Beltsville, Md. 20705 U.S.A. *Associated library:* National Agricultural Library, Beltsville, Md. 20705 U.S.A.

Subject coverage: agriculture, including forestry and forest products.

Output: 45,000 citations from 1970-1977 (14,000 citations in 1977). Arranged by subject, titles of the documents, and author. *Format:* full bibliographic citations plus subject headings, CODEN, ISSN, and ISBN. Titles in original language for cataloged books and serials; titles in English only for reprints of articles that are cataloged. *Geographic coverage:* worldwide.

Input: almost all languages included. *Sources (percent):* monographs plus government documents and reports (almost 100).

Indexes: *Author:* monthly, with semiannual and annual cumulations. *Subject:* Library of Congress subject headings, monthly, with semiannual and annual cumulations. *Translation:* index of translated articles.

Data handling: computerized.

Additional services: (through NAL Library) full-size copies, microcopies, library loans.

NATURAL RESOURCES & EARTH SCIENCES

Journal, weekly, $55; 1974-

Contents cumulate into: NTIS BIBLIOGRAPHIC DATA FILE; GOVERNMENT REPORTS ANNOUNCEMENTS and INDEX.

Published by: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Va. 22161 U.S.A. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: natural resource management and surveys, forestry, mineral industries, soil sciences, geology, and geophysics.

Output: 3000 abstracts in 1977. Arranged by subject categories (COSATI). *Format:* full bibliographic citations plus abstracts, source, price, NTIS order number, and sponsoring organization. Titles in English. Abstracts in English. *Geographic coverage:* worldwide on many subjects, but primarily U.S.A.

Input: regularly, abstracts government-sponored research reports that are publicly available. English. *Sources (percent):* government documents and reports—some of which are in the form of dissertations, patents, conference papers, and others (100).

Indexes: *Subject:* annual (about 10 terms per citation, controlled vocabulary, available for examination). *Taxonomic:* included in the subject index. *Report-accession number:* annual.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, print products (such as special bibliographies), full-size copies, microcopies.

NTIS BIBLIOGRAPHIC DATA FILE **NTIS**

Magnetic tapes, biweekly, $4000 plus use charge (available on-line through DIALOG, ORBIT, and BRS); 1970-

Previously known as: CLEARINGHOUSE FOR FEDERAL SCIENTIFIC AND TECHNICAL INFORMATION [CFSTI] (1964-1969). *Contents overlap with:* GOVERNMENT REPORTS ANNOUNCEMENTS & INDEX (GRA&I); NATURAL RESOURCES and EARTH SCIENCES and 25 other abstract newsletters.

Published by: National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Va. 22161 U.S.A. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: science, technology, medicine, and behavioral and social sciences.

Output: 640,000 citations through 1977 (65,000 abstracts in 1977). *Format:* full bibliographic citations plus abstracts, keywords, subject category codes, source, price, geographic descriptors, GRA&I citation cross-reference, NTIS order number, and sponsoring organization. Titles in English. Abstracts in English. *Geographic coverage:* worldwide on many subjects, but primarily U.S.A.

Input: regularly abstracts government-sponsored research reports that are publicly available. English. *Sources (percent):* government documents and reports, including dissertations, patents, conference papers, and others (100).

Indexes: file searchable by authors, subject categories, descriptors, identifiers (about 10 terms per citation, controlled vocabulary, available for examination), keywords in titles and abstracts, corporate authors, and report numbers.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, print products (such as special bibliographies), full-size copies, microcopies.

PAPER AND BOARD ABSTRACTS **PBA**

Journal, monthly, £40. (£40.); computer print-out, biweekly, £150. (£150.); microforms, price and frequency not given; magnetic tapes, price and frequency not given; 1968-

Previously published as: KENLEY ABSTRACTS (1965-1967).

Published by: Pira, Randalls Road, Leatherhead, Surrey, KT22 7RU, England. *Issuing organization:* same as publisher. *Associated library:* The Library, Pira, Randalls Road, Leatherhead, Surrey, KT22 7RU, England.

Subject coverage: forest products.

Output: about 30,000 citations through 1977 (2518 citations printed, 3200 citations compiled in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, price, and language of document. Titles in English only. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 100 journals, 12 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (65), monographs (2), government documents and reports (1), conference papers (20), manufacturers' catalogs (1), secondary sources (10), other (1).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, on-line search (DIALOG), full-size copies, (library loans to Pira members). Translation services from any language into English.

92 PAPERCHEM

Magnetic tapes (with full text plus keywords, with citations only, with full text only, with keywords only, or any combination of these), monthly, lease agreement required; July 1968-

Contents correspond exactly to: ABSTRACT BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY (July 1968 to present). *Contents overlap with:* IPC LIST OF TRANSLATIONS.

Published by: The Institute of Paper Chemistry, 1043 E. South River Street, P.O. Box 1039, Appleton, Wis. 54912 U.S.A. *Issuing organization:* same as publisher. *Associated library:* Division of Information Services, The Institute of Paper Chemistry, 1043 E. South River Street, P.O. Box 1039, Appleton, Wis. 54912, U.S.A.

Subject coverage: pulp, paper, and related fields.

Output: 11,143 abstracts, 478 cited titles in 1977. Both inverted and direct files available. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, language of original text and of summaries. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 800 journals, 100 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (37), monographs (3), government documents and reports (1), conference papers (10), patents (40), secondary sources (5), translations (3), bibliographies and reviews (1).

Indexes: database searchable by any word in title or abstract, keywords (about 24 per citation), authors, patent countries and patent numbers, document types (book, translation, and other), date-ranging, and languages of original documents (mid-1976 to present). Keywords from THESAURUS OF PAPER TERMS and Supplement 3 (cumulative).

Data handling: computerized.

Additional services: SDI and retrospective retrieval searches (through ORBIT), Annotated Bibliographic Series, full-size copies. Translation services from all languages into English.

93 PESTDOC Pest Control Literature Documentation

PESTDOC

Journal, weekly; abstract book (same as journal but printed on one side of page), weekly; thematic booklets (one of six subject subsets of abstracts books), weekly; microfilm; magnetic tapes, every 3 months—[contact publisher for all pricing]; 1968-

Published by: Derwent Publications Ltd., Rochdale House, 128 Theobalds Rd., London WC1X 8RP, England. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: agricultural and general pest control.

Output: 81,000 citations through 1977 (8000 abstracts in 1977), arranged by Derwent number order. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, and authors' addresses. Titles in original language only for western European languages; titles in English only for non-western European languages. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 750 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), conference papers (30).

Indexes: *Author:* annual. *Subject:* conventional alphabetical and Ring Code, weekly, with cumulations every 3 months (about 12 terms per citation). *Ring Code:* weekly punched index cards with coding for chemical and biological information for use in subject searching.

Data handling: computerized, mechanical, and manual.

Additional services: retrospective retrieval searches, on-line retrieval available through ORBIT.

94 POLLUTION ABSTRACTS

PA

Journal, bimonthly, \$180 (\$180.); magnetic tapes, bimonthly, contact Data Courier for price; 1970-

Published by: Data Courier, Inc., 620 South Fifth Street, Louisville, Ky. 40202 U.S.A. *Issuing organization:* same as publisher.

Subject coverage: environmental pollution.

Output: 51,086 citations through 1977 (6000 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, and subject headings. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 350 journals. List of publications regularly scanned available for examination. Mostly English, French, Russian, Japanese, Spanish, Italian, German. *Sources (percent):* journal articles (60), monographs (15), government documents and reports (5), conference papers (15), other (5).

Indexes: *Author:* bimonthly, with annual cumulations. *Subject:* rotating permuted alphabetical, bimonthly, with annual cumulations (about 10 terms per citation, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: on-line access through DIALOG, ORBIT, BRS, and Information Retrieval Service (European Space Agency).

RECENT PUBLICATIONS OF RANGE RESEARCH

Journal, irregularly, free; 1974-

Published by: U.S. Department of Agriculture, Science and Education Administration, Agricultural Research—Western Region, 2850 Telegraph Avenue, Berkeley, Calif. 94705 U.S.A. *Issuing organization:* same as publisher. *Associated library:* National Agricultural Library, Beltsville, Md. 20705, U.S.A.

Subject coverage: range management.

Output: 142 citations printed in 1977. Arranged by author within geographic region. *Format:* full bibliographic citations plus abstracts, source available, and authors' addresses. Titles in English only. *Geographic coverage:* U.S.A.

Input: content based on publications of U.S. Department of Agriculture, Science and Education Administration on range research. English.

Data handling: manual.

REFERATET
(REFERENCE)

Journal, every 5 weeks, free; 1975-

Published by: Domanverket, Zoja Raskasov, S-17193 Solna, Sweden. *Issuing organization:* Domanverket HK, 79181 Falun, Sweden. *Associated library:* Domanverket Biblioteket, HK, 79181 Falun, Sweden.

Subject coverage: forestry and some forest products.

Output: 536 abstracts in 1977. Arranged by subject. *Format:* bibliographic citations plus abstracts, keywords, subject headings, and price. Titles in Swedish. Abstracts in Swedish. *Geographic coverage:* Scandanavia.

Input: regularly scans one secondary source. Swedish, Norwegian, Danish, English, German, Estonian.

Indexes: *Author:* annual. *Subject:* annual (about three terms per citation, controlled vocabulary, available for examination).

Data handling: manual.

Additional services: full-size copies, library loans. Translation services from Norwegian into Swedish, from Danish into Swedish, from English into Swedish, from German into Swedish, from Estonian into Swedish.

*REFERATIVNYI ZHURNAL—LESOVEDENIE I LESOVODSTVO
(REFERENCE JOURNAL— FOREST SCIENCES AND FOREST MANAGEMENT)

Journal, monthly, $18; 1963-

Contents cumulate into: VINITI database.

Published by: Vsesoyuznyi Institut Nauchno-Tekhnicheskoi Informatsii (VINITI), Baltijskaya ul. 14, 125219 Moscow, A-219, U.S.S.R. *Issuing organization:* same as publisher.

Subject coverage: forestry.

Output: 3267 abstracts in 1978. Arranged by UDC. *Format:* full bibliographic citations plus language(s) of resumes and names of abstracters. Titles in original language and Russian. Abstracts in Russian. *Geographic coverage:* worldwide.

Input: mostly journal articles and conference papers. Almost all languages included.

Indexes: *Author:* annual. *Subject:* annual.

Data handling: computerized.

REFERENCES ON FORESTRY AND FOREST PRODUCTS IN ISRAEL

Leaflet, annual, free on exchange; 1958-

Published by: Division of Forestry, Agricultural Research Organization, Ilanot, D.N. Lev Hasharon, Israel. *Issuing organization:* same as publisher.

Subject coverage: forestry and forest products in Israel.

Output: 926 citations through 1977 (35 cited titles printed, 45 citations compiled in 1977). Arranged by author (listed separately for staff of Forestry Division and others). *Format:* full bibliographic citations. English translations of Hebrew titles; other languages (except for Cyrillic alphabet) in original language. *Geographic coverage:* Israel.

Input: Almost all languages included. *Sources (percent):* journal articles (70), monographs (5), government documents and reports (20), conference papers (5).

Indexes: none issued.

Data handling: manual.

Additional services: full-size copies (only for publications of the Forestry Division), library loans (in Israel only), information on address of author if not on staff of Forestry Division.

99 REMOTE SENSING ON-LINE RETRIEVAL SYSTEM **RESORS**

Computerized database, regularly updated, free bibliographic searches on request; 1975?-

Issuing organization: Canada Centre for Remote Sensing—RESORS, 717 Belfast Rd., Ottawa, Ontario K1A OY 7 CANADA.

Subject coverage: remote sensing, including forest resources.

Output: 12,000 citations through 1977 (5000 cited titles in 1977). Arrangement of output determined by user's search strategy; accessible by subject, titles of documents, author, titles of journal or other primary source, accession number, and author affiliation. *Format:* full bibliographic coverage plus keywords, sources, and authors' addresses. Titles in original language and English or French. *Geographic coverage:* worldwide.

Input: regularly scans 100 journals, 10 secondary sources. English and French. *Sources (percent):* journal articles (30), monographs (2), government documents and reports (20), conference papers (30), manufacturers' catalogs (4), patents (1), secondary sources (13).

Indexes: *Subject:* KWIC with weighted terms (about 10 terms per citation, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies, library loans, translations of original documents.

100 RESOURCE INVENTORY NOTES— CURRENT LITERATURE **RIN**

Journal, every 1 to 2 months, free; 1976-

Previously published as: INFO ON ITEMS OF INTEREST, RESOURCE INVENTORY NOTES (1975-1976) [published by the Forest Service U.S. Department of Agriculture.]

Published by: U.S. Department of Interior, Bureau of Land Management, D 340, Denver Service Center, Denver Federal Center, Bldg. 50, Denver, Colo. 80225 U.S.A. *Issuing organization:* same as publisher.

Subject coverage: natural resources inventory.

Output: 227 cited titles in 1977. Arranged by subject. *Format:* bibliographic citations plus sources. Titles in original language. *Geographic coverage:* worldwide (but primarily U.S.A.).

Input: regularly scans three or four journals, seven secondary sources. Almost all languages included. *Sources (percent):* journal articles (5), monographs (35), government documents and reports (55), conference papers (5).

Data handling: manual.

101 REVIEW OF PLANT PATHOLOGY **RPP**

Journal, monthly, L33 ($155.); microform, monthly, L33 ($155.); magnetic tapes, monthly, price not given; 1970-

Previously published as: REVIEW OF APPLIED MYCOLOGY (1922-1969). *Contents cumulate into:* CAB ABSTRACTS.

Published by: Commonwealth Agricultural Bureaux, Farnham Royal, Slough SL2 3BN, England. *Issuing organization:* Commonwealth Mycological Institute, Ferry Lane, Kew, Richmond, Surrey TW9 3AF, England. *Associated library:* CMI Library, Ferry Lane, Kew, Richmond, Surrey, TWO 3AF, England.

Subject coverage: plant pathology.

Output: 5560 abstracts, 351 titles printed in 1977. Arranged by subject. *Format:* full bibliographic citations plus abstracts, price, authors' addresses, and ISBN. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 900 journals, 12 secondary sources. List of publications regularly scanned available for examination. Almost all languages included.

Indexes: *Author:* monthly, with annual cumulations. *Subject* monthly, with annual cumulations (about six terms per citation).

Data handling: computerized.

Additional services: SDI, retrospective, retrieval searches, full-scale copies, and other services, as requested.

102 RINGYO RINSAN KANKEI KOKUNAI BUNKEN BUNRUI MOKUROKU, O.D.C. (DOMESTIC LITERATURE RELATED TO FORESTRY AND FOREST PRODUCTS BY OXFORD DECIMAL CLASSIFICATION)

Journal, 20,000 yen, annual; 1972-

Published by: Library, Forestry and Forest Products Research Institute, 1 — Matunosato Kukizaki Ibaraki 305, Japan. *Issuing organization:* same as publisher. *Associated library:* Ringyo Kagaku Shinkosho, c/o Library, Forest and Forest Products Research Institute 1 — Matsunosato Kukizaki, Ibaragi 305, Japan.

Subject coverage: forestry and forest products.

Output: 30,000 citations through 1977 (5000 cited titles in 1977). Arranged by ODC number. *Format:* bibliographic citations plus ODC number. Titles in Japanese. *Geographic coverage:* Japan.

Input: regularly scans 274 journals. Japanese. *Sources (percent):* journal articles (50), government documents and reports (50).

Data handling: manual.

S.A. WATERABSTRACTS

Journal, every 6 months, free; magnetic tapes (WATERLIT BIBL. DATABASE), monthly, price negotiable; 1976-

Previously published as: CURRENT LITERATURE ON WATER (1966-75). *Contents cumulate into:* WATERLIT BIBLIOGRAPHIC DATABASE (WATERLIT).

Published by: South African Water Information Centre, P.O. Box 395, Pretoria, 001, Republic of South Africa. *Issuing organization:* same as publisher. *Associated library:* Centre for Scientific and Technical Information, Council for Scientific and Industrial Research, P.O. Box 395, Pretoria, R.S.A.

Subject coverage: water resources, including forest ecology, forest management, and recreation.

Output: 12,000 citations through 1977 (300 abstracts, 7000 cited titles in 1977). Arranged by titles of documents. *Format:* full bibliographic citations plus keywords, subject headings, source, authors' addresses, and CODEN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide, but with emphasis on southern Africa and articles published in South Africa.

Input: regularly scans 430 journals. English, Afrikaans, Dutch, Flemish, and German. *Sources (percent):* journal articles (90), monographs (0.5), government documents and reports (7.5), conference papers (2).

Indexes: none published with journal, but about 10 to 15 terms per citation in the WATERLIT database, controlled vocabulary.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies, library loans, other services from CSIR-Library.

SAHEL BIBLIOGRAPHIC BULLETIN/ BULLETIN BIBLIOGRAPHIQUE — SBB

Journal, quarterly, free; 1977-

Published by: Sahel Documentation Center, Michigan State University Libraries, East Lansing, Mich. 48824 U.S.A. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: socio-economic development of the Sahel region.

Output: 3000 citations through 1978 (700 citations printed, 1000 citations compiled in 1977). In addition to the bibliography, the bulletin has a section entitled "Communications and Information" for current information on projects, meetings, library news, and other. Arranged by country. *Format:* full bibliographic citations plus keywords, subject headings, and price. Titles in original language only. Abstracts in English and French. *Geographic coverage:* Sahel region of Africa: Chad, Niger, Mali, Upper Volta, Mauritania, The Gambia, Cape Verde Islands, Senegal.

Input: regularly scans 30 journals, 10 secondary sources. French and English. *Sources (percent):* journal articles (15), monographs (25), government documents and reports (25), conference papers (15), other (20).

Indexes: *Author:* quarterly, with annual cumulations. *Subject:* KWOC, quarterly, with annual cumulations (about seven terms per citation, controlled vocabulary, available for examination). *Geographic:* quarterly.

Data handling: manual.

Additional services: full-size copies.

SCHNELLDOKUMENTATIONS— KARTEIDIENST DES ARCHIVS ZELLCHEMING — ZELLCHEMING-KARTEI

Card service, monthly, DM 480 plus postage (DM480 plus postage); 1952-

Contents overlap with: REFERATESCHAU in the journal DAS PAPIER.

Published by: Archiv Zellcheming im Institut für Makromolekulare Chemie, Alexanderstr. 24, D-6100 Darmstadt, W. Germany. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: chemistry of wood and paper.

Output: 2400 cited titles in 1977. Arranged by subject and author. *Format:* bibliographic citations plus keywords. Titles in original language and German. Abstracts in German. *Geographic coverage:* worldwide.

Input: regularly scans 84 journals. List of publications regularly scanned available for examination. Almost all languages included except Russian and Chinese. *Sources (percent):* journal articles (80), monographs (5), conference papers (5), patents (10).

Indexes: *Author:* monthly. *Subject:* KWOC, monthly (two or three terms per citation, controlled vocabulary, available for examination).

Data handling: manual.

Additional services: retrospective retrieval searches, full-size copies, library loans.

106 SCHRIFTTUMSKARTEIDIENST DER BUNDESFORSCHUNGSANSTALT FÜR FORST—UND HOLZWIRTSCHAFT

(TITLE SERVICE OF THE FEDERAL RESEARCH CENTER FOR FORESTRY AND FOREST PRODUCTS)

Card service, every 3 months, DM 204, $100. (DM 204, $100.); 1961-

Published by: Bundesforschungsanstalt für Forst- und Holzwirtschaft—Dokumentation, Leuschnerstr. 91, 2050 Hamburg 80, F.R. of Germany. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: forestry and forest products.

Output: 315,000 citations through 1977 (6800 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus keywords, subject headings, and ODC. Titles in original language and German, some in English; titles in English and French untranslated. *Geographic coverage:* worldwide.

Input: regularly scans 600 journals, five secondary sources. List of publications regularly scanned available for examination. Items in Chinese, Japanese, Indonesian, and other Asian languages excluded unless they have summaries in English, French or German. *Sources (percent):* journal articles (45), monographs (10), government documents and reports (30), conference papers (10), secondary sources (5).

[10]**Indexes:** subject (about nine terms per citation).

Data handling: computerized, mechanical, and manual.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies, library loans.

107 SCIENCE CITATION INDEX(R) SCI(R)

Serial (paperbound volumes), bimonthly with annual hardbound cumulations, $3500. ($3500.); magnetic tapes (SCISEARCH), weekly, $10,000. for citation tapes, $10,000. for source tapes; 1961-

Contents cumulate into: SCISEARCH(R) (On-line equivalent of the SCIENCE CITATION INDEX(R)).

Published by: The Institute for Scientific Information, 325 Chestnut Street, Philadelphia, Pa. 19106 U.S.A. *Issuing organization:* same as publisher.

Subject coverage: science in general.

Output: 505,038 citations in 1977. Arranged by subject (Permuterm Subject Index), author (Source Index), and by cited author (Citation Index). *Format:* bibliographic citations plus all references to the citations. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 3300 journals. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (93), conference papers (7).

Indexes: *Author:* every 2 months, with annual cumulations. *Subject:* permuted subject index using words in title, every 2 months, with annual cumulations (about 33 terms per citation). *Geographic:* semiannual, with annual cumulations. *Citation Index:* designed to use source authors' references or footnotes; abbreviated citations arranged alphabetically according to 'cited' author, followed by notations for 'citing' work(s).

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies (original article tear sheet [OATS(R)] service.

108 SEAMALERT: CURRENT SURFACE-MINED RECLAMATION LITERATURE ALERTING SERVICE

Bulletin, quarterly, free; 1977-

Contents cumulate into: SEAMINFO (cumulative database of SEAMALERT).

Published by: SEAM, Office of Arid Lands Studies, University of Arizona, 845 N. Park Ave., Tucson, Ariz. 85719, U.S.A. *Issuing organization:* same as publisher. *Associated library:* Information Center, Office of Arid Lands Studies, University of Arizona, 845 N. Park Ave., Tucson, Ariz. 85719 U.S.A.

Subject coverage: reclamation of surface-mined land.

Output: 3500 citations through 1977 (2000 citations printed in 1977). Arranged by titles of documents. *Format:* full bibliographic citations plus keywords, source, and price. Titles in English. *Geographic coverage:* U.S.A., with some coverage of mining regions of Canada, Australia, and some European countries.

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[10] Note: Author index, subject index, and geographical index not available to subscribers of title service. Titles arranged by author, subject country, and biological species (tree, insect, fungus species) in the database for question-and-answer services on request.

Input: regularly scans 150 journals, 12 secondary sources. List of publications regularly scanned available for examination. English. *Sources (percent):* journal articles (25), monographs (5), government documents and reports (30), conference papers (30), secondary sources (10).

Indexes: *Author:* quarterly. *Subject:* conventional alphabetical and keyword, quarterly (about 10 terms per citation, controlled vocabulary, available for examination).

Data handling: computerized.

Additional services: retrospective retrieval searches, copies of selected documents, SEAM INFO computer printout on request.

SEL'SKOKHOZIAISTVENNAIA LITERATURA CHEKOSLAVAKII (AGRICULTURAL LITERATURE OF CZECHOSLOVAKIA)

Journal, semiannual, available on exchange; 1962-

Published by: Ustav vedeckotechnickych informaci pro zemedelstvi, Slezska 7, 120 56 Praha 2, Czechoslovakia. *Issuing organization:* same as publisher. *Associated library:* Ustredni zemedelska a lesnicka knihovna, Ustav vedeckotechnickych informaci pro zemedelstvi, Slezska 7, 120 56 Praha 2, Czechoslovakia.

Subject coverage: agriculture in Czechoslovakia.

Output: 350 citations compiled, 123 abstracts printed in 1977. Arranged by subject, author, chapters. *Format:* full bibliographic citations plus abstracts and source. Titles in original language and English, German, French, and Russian. Abstracts in English, German, French, and Russian. *Geographic coverage:* Czechoslovakia.

Input: regularly scans 11 journals. List of publications regularly scanned available for examination. Czech, Slovak. *Sources (percent):* journal articles (80), monographs (5), conference papers (15).

Indexes: *Author:* annual. *Subject:* annual (about three terms per citation).

Data handling: manual.

Additional services: retrospective retrieval searches, full-size copies, library loans. Translation services from Czech and Slovak into English, German, French, Russian, and Spanish.

SELECTED WATER RESOURCES ABSTRACTS SWRA

Journal, bimonthly, price not given; magnetic tapes, bimonthly, price not given; 1968-

Published by: Water Resources Scientific Information Center, Office of Water Research and Technology, U.S. Department of Interior, Washington, D.C. 20240 U.S.A. *Issuing organization:* same as publisher.

Subject coverage: water resources.

Output: 116,000 citations through 1977 (13,000 abstracts printed in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, sources, and authors' addresses. Titles in original language and English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 500 journals. English. *Sources (percent):* journal articles (75), monographs (5), government documents and reports (15), conference papers (5).

Indexes: *Author:* bimonthly, with annual cumulations. *Subject:* bimonthly, with annual cumulations (about 12 terms per citation, controlled vocabulary, available for examination). *Organizational:* bimonthly, with annual cumulations.

Data handling: computerized.

Additional services: retrospective retrieval searches.

SOCIAL SCIENCES IN FORESTRY: A CURRENT SELECTED BIBLIOGRAPHY

Journal, every 4 months, free; 1971-

Previously published as: FORESTRY ECONOMICS: A CURRENT SELECTED BIBLIOGRAPHY (1963-1971).

Published by: Virginia Polytechnic Institute and State University, School of Forestry and Wildlife Resources, Department of Forestry, Blacksburg, Va. 24061 U.S.A. (Anne W. Lauby, ed.). *Issuing organization:* same as publisher.

Subject coverage: social sciences as related to foresty and forest products.

Output: 700 abstracts in 1977. Arranged by subject. *Format:* full bibliographic citations plus abstracts and subject headings. Titles in English. Abstracts in English. *Geographic coverage:* primarily U.S.A.

Input: regularly scans 60 journals, 10 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (55), monographs (5), government documents and reports (20), conference papers (5), secondary sources (15).

Indexes: *Subject:* each issue arranged by subject.

Data handling: manual.

112 SOILS AND FERTILIZERS SF

Journal, monthly, £40 in Commonwealth countries ($185. for non-Commonwealth countries); 1938-

Contents overlap with: FORESTRY ABSTRACTS. *Contents cumulate into:* CAB ABSTRACTS.

Published by: Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, Slough SL2 3BN, England. *Issuing organization:* Commonwealth Bureau of Soils, Rothamsted Experimental Station, HARPENDEN, Herts. AL5 2JQ, England. *Associated library:* same as issuing organization.

Subject coverage: soils, fertilizers.

Output: 2800 citations through 1977 (535 abstracts, 30 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, source, price, authors' addresses, and ISBN. Titles in original and English for Roman alphabet citations; in English translation only for Cyrillic alphabet citations. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 1500 journals, three secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (75), monographs (5), government documents and reports (5), conference papers (10), secondary sources (5).

Indexes: *Author:* monthly, with annual cumulations. *Subject:* KWAC (Keyword and Context), monthly, with annual cumulations (about four or five terms per citation). *Geographic:* geographical descriptors included in subject index.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies.

113 SPORT FISHERY ABSTRACTS

Journal, quarterly, $8.50 ($10.65.); 1955-

Published by: Editorial Office, U.S. Fish and Wildlife Service, Aylesworth Hall, Colorado State University, Fort Collins, Colo. 80523 U.S.A. *Issuing organization:* same as publisher.

Subject coverage: sport fishery research and management.

Output: 25,000 citations through 1977 (2000 abstracts in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, and author's address. Titles in original language. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 450 to 500 journals, one secondary source. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), monographs (10), government documents and reports (10), conference papers (10), secondary sources (1).

Indexes: *Author:* each issue, with annual cumulations. *Subject:* each issue, with annual cumulations (about three to five terms per citation, controlled vocabulary, available for examination). *Geographic:* each issue, with annual cumulations. *Taxonomic:* quarterly, with annual cumulations.

Data handling: computerized.

Additional services: retrospective retrieval searches being developed.

114 STICHWORTVERZEICHNIS WILDBIOLOGIE (KEY-WORD INDEX OF WILDLIFE RESEARCH)

Journal, annual, Sw.Fr. 60., $35. (Sw.Fr. 60., $35.); 1974-

Published by: Swiss Wildlife Information Service, Birchstr. 95, CH-8050, Zurich, Switzerland. *Issuing organization:* same as publisher.

Subject coverage: wildlife.

Output: 3500 citations in 1977. Arranged by author, keywords. *Format:* bibliographic citations plus keywords and authors' addresses. Titles in original language. *Geographic coverage:* worldwide.

Input: regularly scans 440 journals, 10 secondary sources. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), monographs (5), government documents and reports (5), conference papers (10), secondary sources (10).

Indexes: *Author:* annual. *Subject:* KWOC, annual, (controlled vocabulary, available for examination). *Geographic:* annual.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies.

115 TRADA LIBRARY BULLETIN

Journal, monthly, available on exchange; 1974-

Contents cumulate into: TINKER cumulative database.

Published by: The Library, Information and Advisory Department, Timber Research and Development Association, Stocking Lane, Hughenden Valley, High Wycombe, Bucks. HP14 4ND, England. *Issuing organization:* same as publisher. *Associated library:* same as publisher.

Subject coverage: forest products.

Output: more than 2000 cited titles in 1977. Arranged by subject. *Format:* full bibliographic citations plus main subject headings and price. Titles in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 200 journals. List of journals regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (40), monographs (20), government documents and reports (20), conference papers (5), manufacturers' catalogs (1), patents (2), other (12).

Indexes: *Subject:* monthly (about one term per citation).

Data handling: manual.

Additional services: full-size copies of journal articles, library loans to TRADA members.

WATERLIT BIBLIOGRAPHIC DATABASE — WATERLIT

Magnetic tapes, monthly, price negotiable; journal (S.A. Waterabstracts), every 6 months, free; 1976-

Previously published as: CURRENT LITERATURE ON WATER (1966-1975). *Contents overlap with:* S.A. WATERABSTRACTS (includes only articles published in South Africa).

Published by: South African Water Information Centre, P.O. Box 395, Pretoria, 001, Republic of South Africa. *Issuing organization:* same as publisher. *Associated library:* Centre for Scientific and Technical Information, Council for Scientific and Industrial Research, P.O. Box 395, Pretoria, R.S.A.

Subject coverage: water resources, including forest ecology, forest management, and recreation.

Output: 12,000 citations through 1977 (300 abstracts, 7000 cited titles in 1977). Arranged by titles of documents. *Format:* full bibliographic citations plus keywords, subject headings, source, authors' addresses, and CODEN. Titles in English. Abstracts in English. *Geographic coverage:* worldwide (with emphasis on Southern Africa.

Input: regularly scans 430 journals. English, Afrikaans, Dutch, Flemish, and German. *Sources (percent):* journal articles (90), monographs (0.5), government documents and reports (7.5), conference papers (2).

Indexes: *Subject:* about 10 to 15 terms per citation in the database; controlled vocabulary is used.

Data handling: computerized.

Additional services: SDI, retrospective retrieval searches, full-size copies, microcopies, library loans, other services from CSIR-Library.

WESTERN FORESTRY INFORMATION NETWORK'S MONTHLY ALERT — WESTFORNET MONTHLY ALERT

Journal, monthly; computer print-out, annual; microfiche, annual; magnetic tapes, annual, available to qualified users by arrangement; 1978-

Previously published as: CALFORNET MONTHLY ALERT (1973-1975); PACFORNET MONTHLY ALERT (1975-1978). *Contents cumulate into:* WESTFORNET UNION LIBRARY CATALOG.

Published by: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, P.O. Box 245, Berkeley, Calif. 94701 U.S.A., and its three associated libraries. *Issuing organization:* same as publisher. *Associated libraries:* WESTFORNET—Berkeley, Forest Service, U.S. Department of Agriculture, Box 245, Berkeley, Calif. 94701, U.S.A.; WESTFORNET (RM), Forest Service, U.S. Department of Agriculture, 240 West Prospect St., Fort Collins, Colo. 80521, U.S.A.; WESTFORNET (INT), Forest Service, U.S. Department of Agriculture, Forest Service Building, 507 - 25th Street, Ogden, Utah 84401 U.S.A.; WESTFORNET NORTH, Forest Resources Library AQ-15, Bloedel Hall, University of Washington, Seattle, Wash. 98195 U.S.A.

Subject coverage: forestry and forest products.

Output: 18,161 citations through 1977 (1692 cited titles in 1977). Arranged by subject. *Format:* full bibliographic citations plus keywords and subject headings. Titles in original language and English. *Geographic coverage:* Western United States.

Input: regularly scans 30 to 60 journals, 15 to 20 secondary sources. English, a little German, French, and Spanish. *Sources (percent):* journal articles (15), monographs (30), government documents and reports (30), conference papers (20), other (5).

Indexes: *Author:* annual. *Subject:* monthly, with annual cumulations (about three terms per citation, controlled vocabulary, available for examination). *Taxonomic:* monthly.

Data handling: computerized and mechanical.

Additional services: retrospective retrieval searches, full-size copies, library loans.

WILDLIFE REVIEW

Journal, quarterly, $8.75 ($11.00); 1935-

Contents cumulate into: WILDLIFE ABSTRACTS.

Published by: Editorial Office, U.S. Fish and Wildlife Service, Aylesworth Hall, Colorado State University, Fort Collins, Colo. 80523 U.S.A. *Issuing organization:* same as publisher.

Subject coverage: game, fish, and wildlife research and management.

Output: 70,000 citations through 1977 (7000 citations in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, and author's address. Titles in original language. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans 450 to 500 journals, one secondary source. List of publications regularly scanned available for examination. Almost all languages included. *Sources (percent):* journal articles (70), monographs (10), government documents and reports (10), conference papers (10), secondary sources (1).

Indexes: *Author:* each issue, with cumulations published periodically as WILDLIFE ABSTRACTS. *Subject:* each issue, with cumulations published periodically as WILDLIFE ABSTRACTS (about three to five terms per citation, controlled vocabulary, available for examination). *Geographic:* each issue. *Taxonomic:* each issue.

Data handling: computerized.

Additional services: retrospective retrieval searches being developed.

119 WOOD INDUSTRY ABSTRACTS

Journal, bimonthly, $60 ($64); July 1972-

Previously published as: WOOD PRODUCTS INDUSTRY ABSTRACT BULLETIN (July 1971-May 1972). *Contents cumulate into:* ABSTRACT INFORMATION DIGEST SERVICE (maintained by the Forest Products Research Society).

Published by: Engineering Extension Service, College of Engineering, Washington State University, Pullman, Wash. 99164 U.S.A. (Charles F. Adams, Managing Editor). *Issuing organization:* same as publisher. *Associated library:* AIDS, Forest Products Research Society, 2801 Marshall Court, Madison, Wis. 53705 U.S.A.

Subject coverage: forestry and forest products.

Output: 6757 citations through 1977 (1200 citations in 1977). Arranged by subject. *Format:* full bibliographic citations plus abstracts, keywords, subject headings, source, price, and authors' addresses. Titles in English. Abstracts in English. *Geographic coverage:* worldwide.

Input: regularly scans more than 100 journals, five secondary sources. List of publications regularly scanned available for examination. English, French, German, Slovak, Russian, and Japanese. *Sources (percent):* journal articles (35), monographs (1), government documents and reports (20), conference papers (3), manufacturers' catalogs (3), patents (35), secondary sources (3).

Indexes: *Author:* annual. *Subject:* KWOC, bimonthly, with annual cumulations (controlled vocabulary, available for examination from F.P.R.S., Madison, Wis. 53705 U.S.A.). *Taxonomic:* annual.

Data handling: manual.

120 WORLD TRANSINDEX

Journal, monthly, Dfl. 650, $290; 1978-

Previously published as: WORLD INDEX OF SCIENTIFIC TRANSLATIONS AND LIST OF TRANSLATIONS NOTIFIED TO THE INTERNATIONAL TRANSLATIONS CENTRE (1967-1977); TRANSATOM BULLETIN (1960-1977); BULLETIN SIGNALETIQUE—TRADUCTIONS (1952-1977).

Published by: International Translations Centre, 101 Doelenstraat, 2611 NS Delft, The Netherlands (D. van Bergeijk, Director). *Issuing organization:* same as publisher.

Subject coverage: translations of items on all fields of science and technology.

Output: 25,691 cited titles in 1978. Arranged by subject, titles of documents, author. *Format:* bibliographic citations plus source of availability of translations. *Geographic coverage:* worldwide.

Input: mostly east-European or Asiatic.

Indexes: *Author:* monthly, with annual cumulations. *Subject:* monthly. *Source index:* monthly.

Data handling: computerized.

Additional services: information service on availability of translations.

INDEXES

Title

The current title in language of origin for each of the 120 entries in this directory appears in capital letters with an index number in the left margin. Associated titles (previous titles, title variations, translations of titles, or the names of other services with which the entry overlaps or into which it cumulates) are indented, printed in lowercase, and are followed by the index number(s) of the main title(s) with which they are connected. The index number refers to the location of the entry in the *Documentation Services* section. All other indexes are keyed to this number.

1 ABI/INFORM
2 ABSTRACT BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY
3 ABSTRACT INFORMATION DIGEST SERVICE
  Abstracted Business Information (1)
4 ABSTRACTS—U.S. INTERNATIONAL BIOLOGICAL PROGRAM ECOSYSTEM ANALYSIS STUDIES
  Abstracts—US/IBP Ecosystem Analysis Studies (4)
5 ABSTRACTS OF BULGARIAN SCIENTIFIC LITERATURE (AGRICULTURE AND FORESTRY, VETERINARY MEDICINE) SERIES A: PLANT BREEDING AND FOREST ECONOMY
6 ABSTRACTS OF ENTOMOLOGY
7 ABSTRACTS OF MYCOLOGY
8 ABSTRACTS ON HEALTH EFFECTS OF ENVIRONMENTAL POLLUTANTS
9 ABSTRACTS ON TROPICAL AGRICULTURE
10 ACCESSIONS BULLETIN (TROPICAL PRODUCTS INSTITUTE)
  Ag-econ database (13)
11 AGRARMETEOROLOGISCHE BIBLIOGRAPHIE
12 AGRIASIA: A CURRENT BIBLIOGRAPHY OF SOUTHEAST ASIAN AGRICULTURAL LITERATURE
  Agricola (13, 88)
  Agricultural Index of Latin America and the Caribbean (78)
  Agricultural Literature of Czechoslovakia (109)
13 AGRICultural On-Line Access
14 AGRINDEX
  Agrinter (19)
  Agris (14, 19, 60)
15 AIKAKAUSLEHTIKATSAUS—TIDSKRIFTSOVERSIKT
  Alerta al Dia-Dasonomia (78)
  American Doctoral Dissertations (47)
  Applied Ecology Abstracts (56)
16 APPLIED ECOLOGY ABSTRACTS: STUDIES IN RENEWABLE NATURAL RESOURCES
  Aquatic Biology Abstracts (17)
7 AQUATIC SCIENCES AND FISHERIES ABSTRACTS—PART I: BIOLOGICAL SCIENCES AND LIVING RESOURCES
  Aquatic Sciences and Fisheries Information System (17)
8 ASSISTANCE WITH ARBORICULTURAL READING
  Assistance with Research Reading (18)
  BA Previews (34)
  Bibliografia Agricola Latinoamericana y del Caribe (78)
9 BIBLIOGRAFIA AGROPECUARIA VENEZOLANA
  Bibliografia Brasileira de Agricultura (21)
0 BIBLIOGRAFIA BRASILEIRA DE BOTANICA
1 BIBLIOGRAFIA BRASILEIRA DE CIENCIAS AGRICOLAS
2 BIBLIOGRAFIA BRASILEIRA DE ZOOLOGIA

23 BIBLIOGRAFIA IN CIENCIAS FORESTALES

Bibliografia Mensal IPEF (80)

Bibliographical Bulletin (Centre Technique du Bois) (39)

24 BIBLIOGRAPHIE DER PFLANZENSCHUTZ—LITERATUR, NEUE FOLGE

Bibliographie Relatif aux Irrigations, au Drainage, a la Regularisation des Cours d'Eau et la Maitrise de Crues (25)

Bibliographien des Deutschen Wetterdienstes (11)

Bibliography of Agriculture (13)

Bibliography on Forest Sciences (23)

25 BIBLIOGRAPHY OF IRRIGATION, DRAINAGE, RIVER TRAINING AND FLOOD CONTROL

Bibliography of Plant Protection Literature, new series (24)

26 BIBLIOGRAPHY OF SYSTEMATIC MYCOLOGY

27 BILIMSEL VE TEKNIK YAYINZAR AYLIK DUYURU BULTENI

28 BILTEN DOKUMENTACIJE (SERIJA D4) INDUSTRIJA TEKSTILA I PAPIRA

29 BILTEN DOKEMENTACIJE (SERIJA A3) SUMARSTVO I DRVNA INDUSTRIJA

30 BIODETERIORATION RESEARCH TITLES

31 BIOLOGICAL ABSTRACTS

32 BIOLOGICAL ABSTRACTS/RRM (REPORTS, REVIEWS, MEETINGS)

Biological Abstracts on Tape (31, 33)

Biome Abstracts—U.S./IBP Ecosystem Analysis (4)

Bioresearch Index (32)

Bioresearch Titles (32)

Bioresearch Today (31)

33 BIORESEARCH TODAY—PESTICIDES

34 BIOSIS PREVIEWS

35 BOLETIM BIBLIOGRAFICO—CELULOSE NIPO-BRASILEIRA S.A.

36 BOLETIN BIBLIOGRAFICO/BIBLIOGRAPHICAL BULLETIN, INSTITUTO LATINO AMERICANO DE INVESTIGACION Y CAPACITACION

Boletin Bibliografico del Instituto Forestal Latino-Americano de Investigacion y Capacitacion (36)

Boletin Bibliografico Editado por el Instituto Forestal Latino-Americano (36)

37 BOLETIN BIBLIOGRAFICO Y DOCUMENTAL/ESCUELA TECNICA SUPERIOR DE INGENIEROS DE MONTES

Brazilian Bibliography of Agricultural Sciences (21)

Brazilian Bibliography of Botany (20)

Brazilian Bibliography of Zoology (22)

38 BULETIN DE INFORMARE—SERIE: SILV.—IND. LEMNULUI

39 BULLETIN BIBLIOGRAPHIQUE (CENTRE TECHNIQUE DU BOIS)

Bulletin of Documentation (series A3) Forestry and Wood Industry (29)

Bulletin of Documentation (series D4) Textile and Paper Industry (28)

Bulletin of the Institute of Paper Chemistry (2)

Bulletin Signaletique—Traductions (120)

40 BULLETIN SIGNALETIQUE 370: BIOLOGIE ET PHYSIOLOGIE VEGETALES

41 CA CONDENSATES

CAB Abstracts (26, 63, 64, 76, 101, 112)

Cain (Cataloging and Indexing records) (13)

Calfornet Monthly Alert (117)

42 CANADA WATER

Card Title Service, Commonwealth Forestry Bureau (64)

43 CHEMICAL ABSTRACTS

44 CHEMICAL TITLES

45 CHEMICAL-BIOLOGICAL ACTIVITIES

46 CIMFORDITASOK KULFOLDI SZAKFOLYOIRATOKBOL

Clearinghouse for Federal Scientific and Technical Information (90)

47 COMPREHENSIVE DISSERTATION INDEX

48 CONFERENCE PAPERS INDEX

49 CURRENT AWARENESS BULLETIN OF EDITED REFERENCES

Current Bibliography for Aquatic Sciences and Fisheries (17)

50 CURRENT CONTENTS/AGRICULTURE, BIOLOGY AND ENVIRONMENTAL SCIENCES

Information Bulletin, Univ. of Agriculture, Brno. (79)

- CURRENT CONTENTS/LIFE SCIENCES
    - Current Contents/Agriculture, Food and Veterinary Sciences (50)
    - Current Contents/Pharmaceutical Publications (51)
    - Current Contents/Your Weekly Guide to the Chemical, Pharmaco-Medical and Life Sciences (51)
- CURRENT LITERATURE (JOURNAL OF FORESTRY)
    - Current Literature on Water (103, 116)
- CURRENT PACKAGING ABSTRACTS
    - Current Programs (48)
    - Current Surface-Mined Reclamation Literature Alerting Service (108)
    - Current Titles in Turkish Science (27)
    - Dictionary Catalog of the Agricultural Library (88)
    - Dissertation Abstracts International (47)
    - Domestic (Japanese) Literature Related to Forestry and Forest Products (102)
- ECOLOGICAL ABSTRACTS
- ECOLOGY AND ENVIRONMENT
- ENTOMOLOGY ABSTRACTS
    - Environment (42)
- ENVIRONMENT ABSTRACTS
    - Environment Information Access (57, 81)
    - Environmental Health and Pollution Control (59)
    - EPA Publications Bibliography (75)
- EPA PUBLICATIONS BIBLIOGRAPHY, QUARTERLY ABSTRACT BULLETIN
- EXCERPTA MEDICA—SECTION 46
- FAO DOCUMENTATION CURRENT BIBLIOGRAPHY
- FERTILIZER ABSTRACTS
- FISH AND WILDLIFE REFERENCE SERVICE NEWSLETTER
- FOREST PRODUCTS ABSTRACTS
- FORESTRY ABSTRACTS
- FORESTRY COMMISSION LIBRARY REVIEW
    - Forestry Economics: A Current Selected Bibliography (111)
- FORESTRY THESES ACCEPTED BY COLLEGES AND UNIVERSITIES IN THE UNITED STATES
- FORSKNINGS—OCH FORSOKMEDDELANDEN FRAN INSTITUTIONER PA JORDBRUKETS TRADGARDSODLINGENS, SKOGENS M FL. OMRADEN
    - Forsknings Och Forsoksmeddelanden. Offentliggjorda Resultat M. M. Fran Institutioner pa Jordbrukets, Tradgardsodlingens, Skogens M. Fl. Omraden (67)
- GEO ABSTRACTS—PART A: LANDFORMS AND THE QUARTERNARY
    - Geo Abstracts—Part B: Biogeography and Climatology (54)
- GEO ABSTRACTS—PART B: CLIMATOLOGY AND HYDROLOGY
- GEO ABSTRACTS—PART C: ECONOMIC GEOGRAPHY
- GEO ABSTRACTS—PART D: SOCIAL AND HISTORICAL GEOGRAPHY
- GEO ABSTRACTS—PART E: SEDIMENTOLOGY
- GEO ABSTRACTS—PART F: REGIONAL AND COMMUNITY PLANNING
- GEO ABSTRACTS—PART G: REMOTE SENSING AND CARTOGRAPHY
    - Geographical Abstracts—Part A: Geomorphology (68)
    - Geographical Abstracts—Part B: Biogeography and Climatology (54, 69)
    - Geographical Abstracts—Part C: Economic Geography (70)
    - Geographical Abstracts—Part D: Social Geography (71)
    - Geographical Abstracts—Part D: Social Geography and Cartography (71)
    - Geomorphological Abstracts (68)
- GOVERNMENT REPORTS ANNOUNCEMENTS & INDEX
- HERBAGE ABSTRACTS
    - ICID Bibliography (25)
- INDEX TO SCIENTIFIC REVIEWS
    - Indexes of State Research database (62)
- INDICE AGRICOLA DE AMERICA LATINA Y EL CARIBE
    - Information on Items of Interest, Resource Inventory Notes (100)
- INFORMACNI ZPRAVODAJ VSZ BRNO
    - Information Bulletin—Series: Silviculture and Woodworking Industries (38)
    - Information Bulletin, Univ. of Agriculture, Brno (79)

International Biodeterioration Bulletin—Reference Index Supplement (30)
IPC List of Translations (2, 92)
80 IPEF—BIBLIOTECA
Kenley Abstracts (91)
Key to Turkish Science (27)
Key-Word Index of Wildlife Research (114)
Knizni a Dokumentacni (79)
81 LAND USE PLANNING ABSTRACTS
82 LIBRARY ACCESSIONS—WESTERN FOREST PRODUCTS LABORATORY, FORINTEK CANADA CORP.
Library Accessions—Western Forest Products Laboratory, Environment Canada (82)
Library Reference Service Newsletter (62)
List of Publications of Swedish Research Institutions in Agriculture, Horticulture, Forestry, and Related Fields (67)
Masters Abstracts (47)
83 MELDETJENESTEN, LANDBRUKSDEPARTEMENTETS OPPLYSNINGSTJENESTE
84 MELDETJENESTEN, DET NORSKE SKOGSELSKAP
Meteorological Abstracts and Bibliography (85)
85 METEOROLOGICAL AND GEOASTROPHYSICAL ABSTRACTS
86 MONTHLY ACCESSIONS LIST (U.K.) NATIONAL METEOROLOGICAL LIBRARY
Monthly Bibliography (86)
87 MUSZAKI LAPSZEMLE. FAIPAR. PAPIR—ES NYOMDAIPAR
National Agricultural Bibliography Series (12)
88 NATIONAL AGRICULTURAL LIBRARY CATALOG
89 NATURAL RESOURCES & EARTH SCIENCES
90 NTIS BIBLIOGRAPHIC DATA FILE
O.D.C. Ringyo Rinsan Kankei Kokunai Bunken Bunrui Mokuroku (102)
Orlook (4)
Pacfornet Monthly Alert (117)
Packaging Bulletin (53)
91 PAPER AND BOARD ABSTRACTS
92 PAPERCHEM
Papier, Das (105)
Pascal (40)
93 PESTDOC PEST CONTROL LITERATURE DOCUMENTATION
94 POLLUTION ABSTRACTS
Programme Applique a la Selection et a la Compilation Automatique de la Litterature (40)
95 RECENT PUBLICATIONS OF RANGE RESEARCH
Referateschau (105)
96 REFERATET
97 REFERATIVNYI ZHURNAL—LESOVEDENIE I LESOVODSTVO
Reference (96)
98 REFERENCES ON FORESTRY AND FOREST PRODUCTS IN ISRAEL
99 REMOTE SENSING ON-LINE RETRIEVAL SYSTEM
Reporting Service, Ministry of Agriculture Information Service (83)
Reporting Service, Norwegian Forest Society (84)
100 RESOURCE INVENTORY NOTES—CURRENT LITERATURE
Review of Applied Mycology (101)
101 REVIEW OF PLANT PATHOLOGY
102 RINGYO RINSAN KANKEI KOKUNAI BUNKEN BUNRUI MOKUROKU O.D.C.
103 S. A. WATERABSTRACTS
104 SAHEL BIBLIOGRAPHIC BULLETIN/BULLETIN BIBLIOGRAPHIQUE
105 SCHNELLDOKUMENTATIONSKARTEIDIENST DES ARCHIVS ZELLCHEMING
106 SCHRIFTTUMSKARTEIDIENST DER BUNDESFORSCHUNGSANSTALT FUR FORST—UND HOLZWIRTSCHAFT
107 SCIENCE CITATION INDEX
Scisearch (50, 51, 77, 107)
108 SEAMALERT: CURRENT SURFACE-MINED RECLAMATION LITERATURE ALERTING SERVICE
Seaminfo (108)

SEL'SKOKHOZIAISTVENNAIA LITERATURA CHEKOSLAVAKII
SELECTED WATER RESOURCES ABSTRACTS
SOCIAL SCIENCES IN FORESTRY: A CURRENT SELECTED BIBLIOGRAPHY
SOILS AND FERTILIZERS
SPORT FISHERY ABSTRACTS
STICHWORTVERZEICHNIS WILDBIOLOGIE
  Technical Abstracts: Woodworking Industry; Paper and Printing Industry (87)
  Temel ve Uygulamali Bilimler Aylik Bibliyografya duyurusu (27)
  Tinker (115)
  Title Service of the Federal Research Center for Forestry and Forest Products (106)
TRADA LIBRARY BULLETIN
  Transatom Bulletin (120)
  Tropical Abstracts (9)
  U.S. Government Research and Development Reports (75)
  U.S. IBP Abstracts (4)
  U.S. IBP Analysis of Ecosystems Program Interbiome Abstracts (4)
  U.S. Government Research Reports (75)
  US/IBP Abstracts (4)
  Viktigare Skogliga Uppsatser I Nyutkomna Utlandska Tidskrifter (67)
  Viniti database (97)
  Waste Materials Biodegradation Research Titles (30)
WATERLIT BIBLIOGRAPHIC DATABASE
  Weekly Survey of Periodicals (15)
WESTERN FORESTRY INFORMATION NETWORK'S MONTHLY ALERT
  Westfornet Monthly Alert (117)
  Westfornet Union Library Catalog (117)
  Wildlife Abstracts (118)
WILDLIFE REVIEW
WOOD INDUSTRY ABSTRACTS
  Wood Products Industry Abstract Bulletin (119)
  World Index of Scientific Translations and List of Translations Notified to the International Translations Centre (120)
WORLD TRANSINDEX

ronyms and Title Abbreviations

R, 18
PC, 2
A, 16
ECON database, 13
RIASIA, 12
RICOLA, 13, 88
RINDEX, 78
RINTER, 19
RIS, 14, 19, 60
S, 3
A, 17
IS, 17
., 9
, 39
T., 30
RRM, 6-8, 32
PREVIEWS, 34
Bib. Doc ETSIM, 37
43
ABSTRACTS, 63, 64, 76, 101, 112
ER, 49, 65
on, 41
CAIN, 13
CALFORNET MONTHLY ALERT, 117
CBAC, 45
CC/AB&ES, 50
CC/LS, 51
CDI, 47
CFSTI, 90
CIMFORDITASOK, 46
CPA, 53
CPI, 48
CT, 44
CWA, 42
EMBASE section 46, 59
EPA PUBLICATIONS BIBLIOGRAPHY, 75
FA, 64
FAO DOC, 60
Fert. Abstr., 61
FORSKNING OCH FORSOK, 67
FPA, 63
FWRS, 62
GRA&I, 75
HEEP, 8, 31, 32
IBBRIS, 30
ICID BIBLIOGRAPHY, 25

IPC LIST OF TRANSLATIONS, 2, 92
ISR, 77
IZ, 79
LUPA, 81
MGA, 85
NTIS, 90
NTIS BIBLIOGRAPHIC DATA FILE, 75, 89
ORLOOK, 4
PA, 94
PACFORNET MONTHLY ALERT, 117
Pap. Board Abstr., 91
PAPERCHEM, 2
PASCAL, 40
PESTDOC, 93
RESORS, 99
RIN, 100
RPP, 101
S.A. WATERABSTRACTS, 116
SBB, 104
SCHRIFTTUMSKARTEIDIENST DER BFH, 106
SCI, 107
SCISEARCH, 50, 51, 77, 107
SEAMINFO, 108
SF, 112
SWRA, 110
TINKER, 115
US/IBP ABSTRACTS, 4
VINITI database, 97
WATERLIT, 103, 116
WESTFORNET MONTHLY ALERT, 117
WESTFORNET UNION LIBRARY CATALOG, 117
ZELLCHEMING-KARTEI, 105

Subject

This index contains 50 subject headings (from AGRICULTURE to WOOD CHEMISTRY) printed in capital letters. It contains 44 cross references (from Aquatic biology to Zoology) printed in lowercase and indented. Because documentation services generally cover a broad range of subject matter, the 120 entries in this directory have been indexed under one or more—usually more—of the 50 broad subject headings. The cross references are synonymous or more specific terms that may be helpful but that do not represent the full subject coverage of the document service.

AGRICULTURE, 5, 11-14, 19, 21, 45, 50, 51, 60, 77-79, 83, 88, 93, 109. *See also* TROPICAL AGRICULTURE
  Aquatic biology, *see* WILDLIFE, GAME AND FISH MANAGEMENT
ARBORICULTURE, 18. *See also* AGRICULTURE, SILVICULTURE
  Behavioral sciences, *see* SOCIAL SCIENCES, RECREATION
  Biochemistry, *see* CHEMISTRY AND BIOCHEMISTRY
  Biological deterioration, *see* CHEMISTRY AND BIOCHEMISTRY; WOOD CHEMISTRY; PRESERVATION, SEASONING
BIOLOGY, 31-34, 48, 50, 51. *See also* SCIENCE AND TECHNOLOGY, CHEMISTRY AND BIOCHEMISTRY
BOTANY, 20, 40. *See also* SCIENCE AND TECHNOLOGY, BIOLOGY, SILVICULTURE, AGRICULTURE, FOREST ECOLOGY
  Cartography, *see* GEOGRAPHY AND LAND USE PLANNING
  Cellulose, *see* WOOD CHEMISTRY, CHEMISTRY AND BIOCHEMISTRY
CHEMISTRY AND BIOCHEMISTRY, 2, 30, 41, 43-45, 55. *See also* PAPER CHEMISTRY, WOOD CHEMISTRY
  Climatology, *see* METEOROLOGY
  Community planning, *see* GEOGRAPHY AN
    LAND USE PLANNING
  Cosmetics, *see* MEDICINE, HEALTH, PHARM
COLOGY, COSMETICS
DESERT, 4
  Deterioration of biological materials, *see* CHEMI
TRY AND BIOCHEMISTRY; WOOD CHEMISTR
PRESERVATION, SEASONING
  Ecology, *see* FOREST ECOLOGY, ENVIRONME
    TAL SCIENCES
ECONOMICS, 1, 70, 104, 111. *See also* FORES
ECONOMICS
  Endangered species, *see* WILDLIFE, GAME AN
    FISH MANAGEMENT
  Energy, *see* WOOD AS AN ENERGY SOURCE
  Engineering, *see* FOREST MANAGEMENT
ENTOMOLOGY, 6, 56. *See also* INSECTS, DISEAS
AND DAMAGE
ENVIRONMENTAL POLLUTION, 8, 59, 94. *See al*
FOREST ECOLOGY
ENVIRONMENTAL SCIENCES, 4, 50, 54, 55, 57, 5
See also FOREST ECOLOGY
FERTILIZERS, INCLUDING FOREST FERTILIZ
TION, 61, 112. *See also* FOREST MANAGEMENT
FIRE, 1, 4, 7, 8, 12-14, 16, 23, 24, 29, 31, 34, 36-39, 42, 4
48, 52, 54, 57, 58, 60, 70, 71, 74-76, 78-81, 85-87, 89, 9
94, 96, 97, 99, 100, 104, 106, 111, 119
  Fisheries, sport, *see* WILDLIFE, GAME AND FIS
    MANAGEMENT
  Flood control, *see* WATER RESOURCES AN
    MANAGEMENT
FOREST ECOLOGY, 1, 2, 4, 5, 7-9, 11-14, 16, 17, 2
23-27, 29, 31-34, 36-38, 40-46, 48, 52, 54-62, 67-69, 7
74-76, 78-81, 85-87, 89, 90, 92, 94, 96-100, 102-104, 10
108-112, 114, 116, 119
FOREST ECONOMICS, 1, 2, 5, 9, 12, 14, 16, 20, 23, 2
36-38, 42, 46, 48, 52, 54, 57, 60, 61, 67, 70, 74, 75, 78-8
87, 89, 90, 92, 96, 97, 99, 102, 104, 106, 108, 109, 111, 1
  Forest engineering, *see* FOREST MANAGEMEN

REST MANAGEMENT, 1-5, 8, 9, 12-14, 16, 23, 25, 29, 31-34, 36-38, 42, 46, 48, 52, 54, 57-61, 67, 70, 73-76, 78-82, 85, 89, 90, 92, 94, 96-100, 102-104, 106, 108-112, 116, 119

REST PRODUCTS, 3, 5, 10, 12, 13, 15, 23, 29, 30, 35, 36-39, 46-52, 60, 63-67, 75, 77, 78, 80, 82, 84, 87, 88, 90, 94, 96, 98, 102, 106, 107, 111, 115, 117, 119, 120

Forest resources, *see* FOREST MANAGEMENT, GEOGRAPHY AND LAND USE PLANNING

RESTRY, 4, 5, 12-15, 19, 23, 29, 31, 32, 34, 36-38, 46-52, 54, 57, 58, 60, 64-67, 71, 74, 75, 77-81, 84, 88-90, 94, 96-98, 101, 102, 106, 107, 111, 117, 119, 120

Game management, *see* WILDLIFE, GAME AND FISH MANAGEMENT

OGRAPHY AND LAND USE PLANNING, 70, 71, 73, 74, 81, 89, 99, 100, 104, 108. *See also* FORESTRY, FOREST MANAGEMENT, WATER RESOURCES AND MANAGEMENT

OLOGY, 68, 69. *See also* SOIL SCIENCE

Herbage, *see* RANGE MANAGEMENT

Hydrology, *see* WATER RESOURCES AND MANAGEMENT

SECTS, DISEASE, AND DAMAGE, 2, 4-9, 12-14, 16, 22-27, 29, 31-34, 36-38, 41-46, 48, 52, 54-58, 60, 67, 71, 74-76, 78-80, 82, 85-87, 89, 90, 92-94, 96-102, 106, 109, 11, 119

Land use planning, *see* GEOGRAPHY AND LAND USE PLANNING

W AND LEGISLATION, 23, 81. *See also* FOREST MANAGEMENT

NAGEMENT SCIENCE, 1, 47, 111. *See also* FOREST MANAGEMENT

Management, game, *see* WILDLIFE, GAME, AND FISH MANAGEMENT

Management, range, *see* RANGE MANAGEMENT

NUFACTURERS' CATALOGS, 91, 99, 115, 119

RKETING OF FOREST PRODUCTS, 1-3, 5, 12, 14, 3, 29, 35-39, 41, 46, 52, 53, 60, 67, 70, 75, 78, 80, 82, 85, 0, 92, 96, 104, 106, 111, 115, 119

DICINE, HEALTH, PHARMACOLOGY, COSMETICS, 8, 45, 48, 51, 59, 75, 77, 90

TEOROLOGY, 11, 25, 69, 85, 86

LLING AND MACHINING OF LUMBER, 3, 5, 8, 12, 3, 29, 35-39, 42, 46, 48, 52, 60, 67, 75, 80, 82, 87, 90, 94, 06, 115, 119

Mining, *see* GEOGRAPHY AND LAND USE PLANNING

COLOGY, 7, 26. *See also* MEDICINE, HEALTH, HARMACOLOGY, COSMETICS

Natural resources inventory management and surveys, *see* GEOGRAPHY AND LAND USE PLANNING, FOREST MANAGEMENT

CKAGING, 2, 53

ER CHEMISTRY, 2, 28, 87, 91, 92, 105. *See also* ULP AND PAPER, WOOD CHEMISTRY, CHEMISTRY AND BIOCHEMISTRY

Pastures, *see* RANGE MANAGEMENT

PATENTS, 2, 3, 10, 14, 15, 41, 43, 45, 55, 61, 82, 87, 92, 99, 105, 115, 119

PESTICIDES AND PEST CONTROL, 24, 33, 93. *See also* INSECTS, DISEASE, AND DAMAGE

Pharmacology, *see* MEDICINE, HEALTH, PHARMACOLOGY, COSMETICS

PHYSICAL AND MECHANICAL PROPERTIES OF WOOD, 2, 3, 5, 9, 12, 14, 23, 27, 29, 35-39, 41, 43, 46, 48, 52, 60, 67, 75, 79, 80, 82, 85, 87, 90, 92, 96, 98, 106, 115, 119

Physiology of plants, *see* BOTANY

Planning, *see* GEOGRAPHY AND LAND USE PLANNING

Plant pathology, *see* INSECTS, DISEASE, AND DAMAGE

Plant physiology, *see* BOTANY, SILVICULTURE

Plant protection, *see* INSECTS, DISEASE, AND DAMAGE; PESTICIDES AND PEST CONTROL

Pollution, environmental, *see* ENVIRONMENTAL POLLUTION

PRESERVATION, SEASONING, 3, 5, 8, 12, 16, 23, 29, 30, 35-39, 41, 43, 44, 46, 48, 52, 55, 60, 67, 75, 80, 82, 85, 87, 90, 93, 106, 115, 119

PULP AND PAPER, 2, 3, 5, 8, 9, 12, 15, 23, 27-29, 35-39, 41-44, 46, 48, 52, 53, 55, 57, 58, 60, 67, 75, 78, 80, 82, 87, 90-92, 94, 96, 105, 106, 110, 111, 115, 119

RANGE MANAGEMENT, 1, 4, 5, 7-9, 12-14, 16, 19, 21-23, 25, 29, 31-34, 36, 37, 42, 46, 48, 52, 54, 57, 58, 60-62, 67, 73, 75, 76, 78, 79, 81, 85, 87, 89, 90, 93-96, 99, 100, 102, 106, 108, 110, 111

Reclamation, 108. *See also* FOREST MANAGEMENT, GEOGRAPHY AND LAND USE PLANNING

RECREATION, 1, 5, 12-14, 16, 23, 25, 29, 31, 34, 36, 42, 46, 48, 52, 54, 57, 59, 60, 62, 67, 70, 71, 73, 75, 76, 78-81, 85, 87, 90, 94, 96, 99, 100, 102, 103, 106, 108, 109, 110, 111, 116, 119

Regional planning, *see* GEOGRAPHY AND LAND USE PLANNING

REMOTE SENSING, 74, 99. *See also* FOREST MANAGEMENT, GEOGRAPHY AND LAND USE PLANNING, WATER RESOURCES AND MANAGEMENT

Resource management and surveys, *see* FOREST MANAGEMENT, GEOGRAPHY AND LAND USE PLANNING, WATER RESOURCES AND MANAGEMENT

SCIENCE AND TECHNOLOGY, 27, 48, 75, 77, 90, 107, 120. *See also* AGRICULTURE, BIOLOGY, BOTANY, CHEMISTRY AND BIOCHEMISTRY, GEOLOGY

Sedimentology, *see* WATER RESOURCES AND MANAGEMENT

SILVICULTURE, 2-5, 7-9, 12-14, 16, 20, 23, 24, 27, 29, 31-34, 36-40, 42, 46, 48, 52, 54, 57, 60, 67, 70, 75, 78-80, 86, 89, 90, 92-94, 96-99, 102, 106, 108, 109, 119

SOCIAL SCIENCES, 1, 70, 71, 75, 77, 90, 104, 111. *See also* RECREATION, GEOGRAPHY AND LAND USE PLANNING

SOIL SCIENCE, 5, 89, 112. *See also* GEOLOGY

SPORT FISHERIES, 62, 113. *See also* WILDLIFE, GAME, AND FISH MANAGEMENT
  Surveys and management, natural resource, *see* GEOGRAPHY AND LAND USE PLANNING
  Technology, *see* SCIENCE AND TECHNOLOGY
  Toxicology, *see* CHEMISTRY AND BIOCHEMISTRY; MEDICINE, HEALTH, PHARMACOLOGY, COSMETICS
TRANSLATIONS, 120
TROPICAL AGRICULTURE, 9, 10. *See also* AGRICULTURE
  Tundra, *see* FOREST ECOLOGY
VENEER, PLYWOOD, COMPOSITE BOARDS, 2, 3, 5, 9, 12, 15, 23, 29, 36-39, 41, 43, 44, 46, 48, 52, 60, 67, 75, 80, 82, 87, 90-92, 96, 106, 111, 115, 119
WATER RESOURCES AND MANAGEMENT, 25, 42, 58, 69, 72, 89, 103, 110, 116
WILDLIFE, GAME, AND FISH MANAGEMENT, 1, 4, 5, 7, 8, 12-14, 16, 17, 19, 22, 24, 25, 27, 29, 31-34, 36, 37, 42, 46, 48, 52, 54, 57, 58, 60, 62, 67, 73, 75, 76, 78-81, 85, 87, 89, 90, 93, 94, 96, 99, 100, 102, 104, 106, 108-111, 113, 114, 118, 119
  Wood, preservation of, *see* PRESERVATION, SEASONING; WOOD CHEMISTRY; CHEMISTRY AND BIOCHEMISTRY
WOOD AS AN ENERGY SOURCE, 2-5, 8, 12, 14, 23, 29, 35-39, 41, 43, 44, 46, 48, 52, 55, 57, 58, 60, 67, 70, 75, 78, 80-82, 85, 87, 90, 92, 94, 96, 99, 104, 106, 111, 115, 119
WOOD CHEMISTRY, 2, 3, 5, 8, 12, 15, 23, 29, 30, 35-44, 46, 48, 52, 55, 67, 75, 79, 80, 82, 87, 90, 92, 94, 105, 106, 115, 119
  Zoology, *see* WILDLIFE, GAME, AND FISH MANAGEMENT

Geographical Coverage

By Region

Asia, 12
Caribbean, 78
Central America, 78
Europe, 28, 29, 37
ICID member countries (almost worldwide), 25
Latin America, 36, 37
North America, 28, 29, 52
Northern Europe, 83, 84
Sahel region of Africa, 104
South America, 78
Southern Africa, 103
Temperate regions, particularly Great Britain, 49, 65
Tropical and subtropical regions, 9, 10, 12, 78, 104

By Country

Australia, 108
Bangladesh, 12
Brazil, 20-22
Bulgaria, 5
Canada, 37, 42, 82, 108
Cape Verde Islands, 104
Chad, 104
Czechoslovakia, 79, 109
Gambia, The, 104
Great Britain, 49, 65
Hong Kong, 12
Indonesia, 12
Israel, 98
Japan, 102
Korea, Republic of, 12
Malaysia, 12
Mali, 104
Mauritania, 104
Mexico, 78
Niger, 104
Philippines, 12
Scandinavia, 96
Senegal, 104
Singapore, 12
South Africa, 103
Spain, 37
Sweden, 67
Thailand, 12
Turkey, 27
United States of America, 4, 37, 58, 62, 66, 75, 82, 89, 90, 95, 100, 108, 111, 117
Upper Volta, 104
Venezuela, 19
Worldwide, 1-3, 6-8, 10, 11, 13-18, 23, 24, 26, 30-34, 39-41, 43-48, 50, 51, 53-57, 59-61, 63, 64, 68-74, 76, 77, 80, 81, 85-94, 97, 99-101, 103, 105-107, 110, 112-116, 118-120

Country of Origin

Argentina

BIBLIOGRAFIA EN CIENCIAS FORESTALES, 23

Brazil

BIBLIOGRAFIA BRASILEIRA DE BOTANICA, 20
BIBLIOGRAFIA BRASILEIRA DE CIENCIAS AGRICOLAS, 21
BIBLIOGRAFIA BRASILEIRA DE ZOOLOGIA, 22
BOLETIM BIBLIOGRAFICO—CELULOSE NIPO-BRASILEIRA S.A., 35
IPEF—BIBLIOTECA, 80

Bulgaria

ABSTRACTS OF BULGARIAN SCIENTIFIC LITERATURE (AGRICULTURE AND FORESTRY, VETERINARY MEDICINE) SERIES A: PLANT BREEDING AND FOREST ECONOMY, 5

Canada

CANADA WATER, 42
LIBRARY ACCESSIONS—WESTERN FOREST PRODUCTS LABORATORY, FORINTEK CANADA CORP., 82
REMOTE SENSING ON-LINE RETRIEVAL SYSTEM, 99

Costa Rica

INDICE AGRICOLA DE AMERICANA LATINA Y EL CARIBE, 78

Czechoslovakia

INFORMACNI ZPRAVODAJ VSZ Brno, 79
SEL'SKOKHOZIAISTVENNAIA LITERATURA CHEKOSLOVAKII, 109

Finland

AIKAKAUSLEHTIKATSAUS—TIDSKRIFTSOVERSIKT, 15

France

BULLETIN BIBLIOGRAPHIQUE (Centre Technique du Bois), 39
BULLETIN SIGNALETIQUE 370: BIOLOGIE ET PHYSIOLOGIE VEGETALES, 40

Germany, Federal Republic of

AGRARMETEOROLOGISCHE BIBLIOGRAPHIE, 19__, 11
BIBLIOGRAPHIE DER PFLANZENSCHUTZ-LITERATUR, NEUE FOLGE, 24
SCHNELLDOKUMENTATIONSKARTEIDIENST DES ARCHIVS ZELLCHEMING, 105
SCHRIFTTUMSKARTEIDIENST DER BUNDESFORSCHUNGSANSTALT FUR FORST UND HOLZWIRTSCHAFT, 106

Hungary

CIMFORDITASOK KULFOLDI SZAKFOLYOIRATOKBOL, 46
MUSZAKI LAPSZEMLE. FAIPAR. PAPIR-ES NYOMDAIPAR, 87.

India

BIBLIOGRAPHY OF IRRIGATION, DRAINAGE, RIVER TRAINING, AND FLOOD CONTROL, 25

Israel

REFERENCES ON FORESTRY AND FOREST PRODUCTS IN ISRAEL, 98

Italy

AGRINDEX, 14
AQUATIC SCIENCES AND FISHERIES ABSTRACTS—PART 1, 17
FAO DOCUMENTATION CURRENT BIBLIOGRAPHY, 60

Japan

RINGYO RINSAN KANKEI KOKUNAI BUNKEN BUNRUI MOKUROKU, O.D.C., 102

Netherlands
ABSTRACTS ON TROPICAL AGRICULTURE, 9
EXCERPTA MEDICA—SECTION 46, 59
WORLD TRANSINDEX, 120

Norway
MELDETJENESTEN, LANDBRUKSDEPARTEMENTETS OPPLYSNINGSTJENESTE, 83
MELDETJENESTEN, DET NORSKE SKOGSELSKAP, 84

Philippines
AGRIASIA: A CURRENT BIBLIOGRAPHY OF SOUTHEAST ASIAN AGRICULTURAL LITERATURE, 12

Romania
BULETIN DE INFORMARE—SERIE: SILV.-IND. LEMNULUI, 38

South Africa, Republic of
S. A. WATERABSTRACTS, 103
WATERLIT BIBLIOGRAPHIC DATABASE, 116

Spain
BOLETIN BIBLIOGRAFICO Y DOCUMENTAL, Escuela Tecnica Superior de Ingenieros de Montes, 37

Sweden
FORSKNINGS—OCH FORSOKSMEDDELANDEN FRAN INSTITUTIONER PA JORDBRUKETS. TRADGARDSODLINGENS, SKOGENS M. FL. OMRADEN, 67
REFERATET, 96

Switzerland
STICHWORTVERZEICHNIS WILDBIOLOGIE, 114

Turkey
BILIMSEL VE TEKNIK YAYINZAR AYLIK DUYURU BULTENI, 27

Union of Soviet Socialist Republics
REFERATIVNYI ZHURNAL—LESOVEDENIE I LESOVODSTVO, 97

United Kingdom
ACCESSIONS BULLETIN (TROPICAL PRODUCTS INSTITUTE), 10
APPLIED ECOLOGY ABSTRACTS: STUDIES IN RENEWABLE NATURAL RESOURCES, 16
ASSISTANCE WITH ABORICULTURAL READING, 18
BIBLIOGRAPHY OF SYSTEMATIC MYCOLOGY, 26
BIODETERIORATION RESEARCH TITLES, 30
CURRENT AWARENESS BULLETIN OF EDITED REFERENCES, 49
ECOLOGICAL ABSTRACTS, 54
ENTOMOLOGY ABSTRACTS, 56
FOREST PRODUCTS ABSTRACTS, 63
FORESTRY ABSTRACTS, 64
FORESTRY COMMISSION LIBRARY REVIEW, 65
GEO ABSTRACTS—PART A: LANDFORMS AND THE QUARTERNARY, 68
GEO ABSTRACTS—PART B: CLIMATOLOGY AND HYDROLOGY, 69
GEO ABSTRACTS—PART C: ECONOMIC GEOGRAPHY: 70
GEO ABSTRACTS—PART D: SOCIAL AND HISTORICAL GEOGRAPHY, 71
GEO ABSTRACTS—PART E: SEDIMENTOLOGY, 72
GEO ABSTRACTS—PART F: REGIONAL AND COMMUNITY PLANNING, 73
GEO ABSTRACTS—PART G: REMOTE SENSING AND CARTOGRAPHY, 74
HERBAGE ABSTRACTS, 76
MONTHLY ACCESSIONS LIST, (U.K.) NATIONAL METEOROLOGICAL LIBRARY, 86
PAPER AND BOARD ABSTRACTS, 91

PESTDOC Pest Control Literature Documentation, 93
REVIEW OF PLANT PATHOLOGY, 101
SOILS AND FERTILIZERS, 112
TRADA LIBRARY BULLETIN, 115

United States of America
ABI/INFORM, 1
ABSTRACT BULLETIN OF THE INSTITUTE OF PAPER CHEMISTRY, 2
ABSTRACT INFORMATION DIGEST SERVICE, 3
ABSTRACTS—U.S. INTERNATIONAL BIOLOGICAL PROGRAM ECOSYSTEM ANALYSIS STUDIES, 4
ABSTRACTS OF ENTOMOLOGY, 6
ABSTRACTS OF MYCOLOGY, 7
ABSTRACTS ON HEALTH EFFECTS OF ENVIRONMENTAL POLLUTANTS, 8
AGRICultural On-Line Access, 13
BIOLOGICAL ABSTRACTS, 31
BIOLOGICAL ABSTRACTS/RRM (REPORTS, REVIEWS, MEETINGS), 32
BIORESEARCH TODAY—PESTICIDES, 33
BIOSIS PREVIEWS, 34
CA CONDENSATES, 41
CHEMICAL ABSTRACTS, 43
CHEMICAL TITLES, 44
CHEMICAL-BIOLOGICAL ACTIVITIES, 45
COMPREHENSIVE DISSERTATION INDEX, 47
CONFERENCE PAPERS INDEX, 48
CURRENT CONTENTS—AGRICULTURE, BIOLOGY AND ENVIRONMENTAL SCIENCES, 50
CURRENT CONTENTS—LIFE SCIENCES, 51
CURRENT LITERATURE (JOURNAL OF FORESTRY), 52
CURRENT PACKAGING ABSTRACTS, 53
ECOLOGY AND ENVIRONMENT, 55
ENVIRONMENT ABSTRACTS, 57
EPA PUBLICATIONS BIBLIOGRAPHY, QUARTERLY ABSTRACT BULLETIN, 58
FERTILIZER ABSTRACTS, 61
FISH AND WILDLIFE REFERENCE SERVICE NEWSLETTER, 62
FORESTRY THESES ACCEPTED BY COLLEGES AND UNIVERSITIES IN THE UNITED STATES, 66
GOVERNMENT REPORTS ANNOUNCEMENTS AND INDEX, 75
INDEX TO SCIENTIFIC REVIEWS, 77
LAND USE PLANNING ABSTRACTS, 81
METEOROLOGICAL AND GEOASTROPHYSICAL ABSTRACTS, 85
NATIONAL AGRICULTURAL LIBRARY CATALOG, 88
NATURAL RESOURCES AND EARTH SCIENCES, 89
NTIS BIBLIOGRAPHIC DATA FILE, 90
PAPERCHEM, 92
POLLUTION ABSTRACTS, 94
RECENT PUBLICATIONS OF RANGE RESEARCH, 95
RESOURCE INVENTORY NOTES—CURRENT LITERATURE, 100
SAHEL BIBLIOGRAPHIC BULLETIN/BULLETIN BIBLIOGRAPHIQUE, 104
SCIENCE CITATION INDEX, 107
SEAMALERT: CURRENT SURFACE MINED RECLAMATION LITERATURE ALERTING SERVICE, 108
SELECTED WATER RESOURCES ABSTRACTS, 110
SOCIAL SCIENCES IN FORESTRY: A CURRENT SELECTED BIBLIOGRAPHY, 111
SPORT FISHERY ABSTRACTS, 113
WESTERN FORESTRY INFORMATION NETWORK'S MONTHLY ALERT, 117
WILDLIFE REVIEW, 118
WOOD INDUSTRY ABSTRACTS, 119

Venezuela
BIBLIOGRAFIA AGROPECUARIA VENEZOLANA, 19
BOLETIN BIBLIOGRAFICO/BIBLIOGRAPHICAL BULLETIN, INSTITUTO LATINO-AMERICANO DE INVESTIGACION Y CAPACITACION, 36

Yugoslavia
BILTEN DOKUMENTACIJE (SERIJA A3) SUMARSTVO I DRVNA INDUSTRIJA, 29
BILTEN DOKUMENTACIJE (SERIJA D4) INDUSTRIJA TEKSTILA I PAPIRA, 28

Publishers and Issuing Organizations

Argentina
Universidad Nacional del Nordeste, Centro de Informacion Bioagropecuario y Forestal, 23

Brazil
Celulose Nipo-Brasileira S.A., Central de Informacoes Tecnicas, 35
Instituto Brasileiro de Informacao em Ciencia e Tecnologia, Biblioteca do IBICT, 20-22
Instituto de Pesquisos e Estudos Florestais (IPEF). Biblioteca, 80

Bulgaria
National Center for Scientific and Technical Information in Agriculture, Food Industry and Forestry, 5

Canada
Canada Centre for Remote Sensing, 99
Water Resources Document Reference Centre (WATDOC), Fisheries and Environment Canada, Inland Waters Directorate, 42
Western Forest Products Laboratory, Forintek Canada Corp., 82

Costa Rica
Centro Interamericano de Documentacion e Informacion Agricola, Instituto Interamericano de Ciencias Agricolas—OEA, 78

Czechoslovakia
Ustav vedeckotechnickych informaci pro zemedelstvi, 109
Ustav vedeckych informaci Vysoke skoly zemedelske v Brne, 79

Finland
Oy Keskulaboratorio—Centrallaboratorium Ab (The Finnish Pulp and Paper Research Institute), Documentation Service, 15

France
Centre National de la Recherche Scientifique, Centre de Documentation, 40
Centre Technique du Bois, 39

Germany, Federal Republic of
Paul Parey, 24
Archiv Zellcheming im Institut fur Makromolekulare Chemie, 105
Bundesforschungsanstalt fur Forst- und Holzwirtschaft—Dokumentation, 106
Deutscher Wetterdienst, 11
Pflanzenkrankheifen und Pflanzenschutz der Biologischen Bundesanstalt für Land- und Forstwirtschaft, Dokumentationsschwerpunkt, 24

Hungary
Erdeszeti es Faipari Egyetem Kozponti Konyvtara, 46
Hungarian Central Technical Library and Documentation Centre, 87
Orszagos Muszaki Konyvtar es Dokumentacios Kozpont, 87

India
International Commission on Irrigation and Drainage (ICID), 25

Israel
Agricultural Research Organization, Division of Forestry, 98

Italy
Food and Agriculture Organization of the United Nations, 14, 17, 60
APIMONDIA, 14

Japan
Forestry and Forest Products Research Institute, Library, 102

Netherlands
Excerpta Medica, 59
International Translations Centre, 120
Koninklijk Instituut voor de Tropen (Royal Tropical Institute), Dep. of Agricultural Research, 9

Norway
Landbruksdepartementets opplysningstjeneste, 83, 84

Philippines
Agricultural Information Bank for Asia, 12
Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), 12

Romania
APIMONDIA, 14
Universitatea din Brasov, Biblioteca Centrala, 38

South Africa, Republic of
South African Water Information Centre, 103, 116

Spain
Escuela Tecnica Superior de Ingenieros de Montes. Biblioteca, 37

Sweden
Kungl. Skogs- och Lantbruksakademien, Biblioteket (The Royal Swedish Academy of Agriculture and Forestry, Library), 67
Domanverket, 96

Switzerland
Swiss Wildlife Information Service, 114

Turkey
Turkiye Bilimsel ve Teknik Dokumantasyon Merkezi (TURDOK), 27

Union of Soviet Socialist Republics
Vsesoyuznyi Institut Nauchno-Tekhnicheskoi Informatsii (VINITI), 97

United Kingdom
Biodeterioration Centre, St. Peter's College. University of Aston, 30
Commonwealth Agricultural Bureaux, 26, 63, 64, 76, 101, 112
Commonwealth Bureau of Pastures and Field Crops, 76
Commonwealth Bureau of Soils, 112
Commonwealth Forestry Bureau, 63, 64
Commonwealth Mycological Institute, 26, 101
Derwent Publications Limited, 93
Forest Research Station, Alice Holt Lodge, 65
Forestry Commission Library, 49
Forestry Commission Research Station, Arboricultural Advisory and Information Service, 18
Information Retrieval Limited, 16, 17, 56
Meteorological Office, National Meteorological Library, 86
Paper, Printing and Packaging Industries Research Association, 91
Timber Research and Development Association (TRADA). The Library, 115

United States of America
American Meteorological Society, 85
Biosciences Information Service (BIOSIS), 6-8, 31-34
Bureau of Land Management, U.S. Department of Interior, 100
Chemical Abstracts Service, the American Chemical Society, 41, 43-45, 55
Data Courier, Inc., 1, 48, 94
Environment Information Center (EIC), 57, 81
Fish and Wildlife Reference Service, Denver Public Library, 62
Fish and Wildlife Service, U.S. Department of Interior, Fort Collins, Colo., 113, 118
Forest Products Research Society, 3
Information Retrieval, Inc., 16, 17
The Institute for Scientific Information, 50, 51, 77, 107
The Institute of Paper Chemistry, 2, 92
National Fertilizer Development Center, Fertilizer Abstracts Service, Tennessee Valley Authority , 61
National Technical Information Service, U.S. Department of Commerce, 58, 75, 89, 90
Oak Ridge National Laboratory, Environmental Sciences Division, 4
Oregon State University Press, 66
Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, 117
Packaging Library, University of California, Davis, 53
Rowman and Littlefield, The Library Division, 88
SEAM, Office of Arid Lands Studies, University of Arizona, 108
Sahel Documentation Center, Michigan State University Libraries, 104
Society of American Foresters, 52
U.S. Department of Agriculture, Agricultural Research—Western Region, 95
U.S. Department of Agriculture, Science, and Education Administration, 13, 88, 95
U.S. Environmental Protection Agency, Library Systems Branch, 58
University Microfilms International, 47
Virginia Polytechnic Institute and State University. School of Forestry and Wildlife Resources, Department of Forestry, 111
Washington State University, College of Engineering. Engineering Extension Service, 119
Water Resources Scientific Information Center, Office of Water Research and Technology, U.S. Department of Interior, 110

Venezuela
Centro Nacional de Investigaciones Agropecurias (CENIAP), Biblioteca Orfila Marquez y Dilia Ramos, 19
Instituto Forestal Latino-Americano de Investigacion y Capacitacion, 36
Red de Informacion para las Ciencias Agropecuarias (REDIAGRO), 19

Yugoslavia
Jugoslovenski Centar za Technicku i Naucnu Dokumentaciju, 28, 29

Language(s) of Input Sources

Afrikaans, 103, 116
Almost all languages are covered, 2, 6-9, 13-17, 24-26, 31-34, 39-41, 43-45, 50, 51, 53-57, 59, 63, 64, 68-74, 76, 77, 80, 81, 85-88, 91-93, 97, 98, 100, 101, 105-107, 111-115, 118
Bahasa-Indonesian, 12
Bulgarian, 5, 29
Chinese, 12
Czech, 28, 29, 79, 109
Danish, 83, 84, 96
Dutch, 18, 36, 103, 116
English, 1, 3, 4, 10-12, 18, 23, 27-30, 36, 37, 42, 47-49, 52, 58, 60-62, 65-67, 75, 82-84, 89, 90, 94-96, 99, 103, 104, 108, 110, 116, 117, 119
Estonian, 96
European languages only, 46
Filipino, 12
Flemish, 103, 116
French, 4, 10, 11, 18, 27-29, 36, 37, 49, 60, 67, 94, 99, 119
German, 4, 10, 11, 18, 27-29, 36, 37, 49, 67, 82-84, 94, 103, 116, 119
Hungarian, 28
Italian, 29, 36, 37, 94
Japanese, 94, 102, 119
Korean, 12
Malay, 12
Norwegian, 83, 84, 96
Polish, 28
Portuguese, 10, 20-22, 36, 78
Romanian, 28

ssian, 4, 28, 29, 94, 119
bo-Croatian, 29
vak, 28, 29, 79, 109, 119
nish, 10, 19, 23, 37, 60, 78, 94
dish, 67, 83, 84, 96
i, 12
kish, 27
stly East-European or Asiatic, 120

nguage(s) in Which stracts Are Published

language submitted for inclusion on AGRIS tapes, 14
ch(Slovak), 79
nish, 83, 84
lish, 1-9, 11, 16, 17, 25, 31, 33, 36, 42, 43, 45, 53-64, 68,
9, 71-76, 79, 81, 85, 89-94, 101, 103, 104, 109-113, 116,
18, 119
nch, 11, 39, 40, 104, 109
man, 11, 105, 109
garian, 87
wegian, 83, 84
sian, 4, 79, 97, 109
o-Croatian, 28
nish, 36
dish, 83, 84, 96

nguages in Which les Are Published

ginal language only, 1, 15, 19-23, 37, 48, 57, 78, 80, 81,
, 100, 104, 114
ginal language and in translation, 9, 12-17, 24, 26-29,
, 39, 40, 46, 47, 49, 54, 56, 60, 63-65, 67-74, 76, 79,
-85, 87, 94, 97-99, 101, 105, 106, 109, 110, 112, 113,
7, 118, 120
garian, 5
ish, 83, 84
lish, 1-10, 12-14, 16-18, 24-27, 30-34, 36, 41-45, 47-66,
-77, 79, 81, 82, 85, 86, 88-95, 98-101, 103, 107-113,
5-119
ish, 15
nch, 24, 25, 39, 40, 59, 99, 109
man, 11, 24, 59, 105, 106, 109, 114
rew, 98
garian, 46, 87
an, 59
nese, 102
wegian, 83, 84
uguese, 20-22, 35, 59, 80
anian, 38
sian, 5, 79, 97, 109
o-Croatian, 28, 29
nish, 35, 36, 59
dish, 67, 83, 84, 96
ish, 27
ern European languages, 86, 93

Additional Services

This index reflects only a partial coverage of the additional services available. It was compiled from sections 4.7 and 4.8 on the questionnaire (*app. B*). If an organization did not respond to these sections, then its additional service(s) will not be indicated here. For instance, there are undoubtedly more than three organizations out of 120 that supply referral services, yet only three indicated this function in sections 4.7 and 4.8. On the other hand, the user of this directory can be confident of the service when the organization has made a point of mentioning it.

Abstract copies, 3
Authors' addresses, 98
Bibliographies, annotated, 2, 64, 92
Bibliographies, special, 30, 58, 75, 85, 89, 90
Chemical Abstracts Service Source Index, 41, 43-45, 55
Computer printout of database, 108
Full-size copies, 1-3, 9, 10, 14-16, 18-24, 26-30, 36, 37, 39, 46, 47, 49-51, 53, 57-60, 62-65, 67, 75-77, 79-82, 86-92, 96, 98, 99, 101, 103-109, 112, 114-117
Indexes of state research, 62
Library loans, 10, 13, 14, 19, 23, 24, 26, 37, 46, 49, 65, 67, 79, 82, 86-88, 96, 98, 99, 103, 105, 106, 109, 116, 117
Microcopies, 12, 14, 20-22, 28, 29, 47, 57-60, 62, 75, 79, 81, 87-90, 99, 103, 106, 116
Newsletter, 42
Numeric data sets, 4
On-line searching, 1, 6-8, 13, 14, 31, 32, 34, 40, 41, 43-45, 47, 48, 55, 59, 63, 64, 76, 90-94, 99, 101, 107, 112
Referral, 61, 62, 67
Research and advisory services, 30, 36
Retrospective retrieval searches, 2-4, 9, 10, 12, 13, 15, 23, 24, 27-30, 34, 36, 37, 39-45, 47, 49-51, 53-55, 57-60, 62-65, 68-77, 79, 81, 86, 87, 89-93, 99, 101, 103, 105-110, 112-114, 116-118
Selective dissemination of information (SDI), 2, 4, 9, 12, 13, 15, 16, 23, 30, 34, 36, 37, 40, 41, 43-46, 49-51, 55-59, 63-65, 75, 80, 81, 86, 87, 89-92, 99, 101, 103, 106, 107, 112, 114, 116
Standard profiles (28 different profiles), 34
Thesaurus, 62
Translations into:
  Any language, 59
  Unspecified languages, 14, 87, 99
  Czech (Slovak), 79
  Dutch, 36
  English, 2, 10, 15, 29, 36, 79, 91, 92, 109
  French, 29, 36, 109
  German, 15, 29, 36, 79, 109
  Russian, 29, 79, 109
  Serbo-Croation, 28, 29
  Spanish, 23, 36, 109
  Swedish, 96
Translations availability, information service on, 120

APPENDIXES

A. Organizations Publishing an Acquisitions List

The following organizations—libraries, documentation centers, and similar institutions—publish an acquisitions list. These organizations do not appear in the main text of this directory for one or more of these reasons:

- The compilers of this directory were not aware of the organization until it was too late to acquire full information.
- The organization was contacted but did not respond to our questionnaire.
- The acquisitions list does not fulfill the requirements for this directory. (See introduction, p. 1, for a list of these requirements.)

Nevertheless, because an acquisitions list can be a particularly useful tool for scanning the literature of an area, these sources are listed here and are organized by country.

This information was obtained from Food and Agricultural Organization of the United Nations(FAO) *AGRIS-Forestry World Catalogue of Information and Documentation Services* (Rome 1979). More detailed information on each organization is supplied in this FAO publication, which may be obtained by writing: Publications Division, Food and Agriculture Organization of the United Nations, Via delle Terme di Caracalla, 00100 Rome, Italy. The four-digit number to the left of each entry is the accession number for that organization in FAO's *World Catalogue*.

Argentina

0003 Biblioteca Central. Av. Belgrano 1912, 4200 Santiago del Estero. Tel: 1955; 5727. Prof. Nestor Urtubey.

Australia

0006 Associated Pulp and Paper Mills Limited, Library. P.O. Box 201, Burnie, Tasmania 7320. Tel: 004-311222. Telex: AA 58575.

0007 Australian National Scientific and Technological Library (ANSTEL). P.O. Box E 333, Canberra, A.C.T. 2600. Tel: 062-621525. Mr. A. Wilson.

0010 CSIRO, Division of Building Research, P.O. Box 56, Highett, Victoria 3190. Tel: 950333. Telex: AA 33766; Cable: BUILDRESEARCH, MELBOURNE. Librarian.

0011 CSIRO, Division of Forest Research, Library. Banks Street, Yarralumla, A.C.T. 2600. Tel: 062-818356. Telex: 62571; Cable: FORESEARCH. Librarian.

0012 Department of Forestry. Box 944, G.P.O., Brisbane, Queensland 4001. Tel: 2292133. Librarian.

0013 Department of Forestry, Australian National University. P.O. Box 4, Canberra, A.C.T. 2600. Tel: 494313. Cable: FORESTRY, NATUNIV. Librarian.

0015 Forests Department Library. 54-58 Barrack Perth 6000, Western Australia. Tel: 3258077. Lib ian, Ms. J.A. O'Neill.

0016 Library, Forests Commission, Victoria. P.O. 4018 G.P.O. Melbourne, Victoria 3001. Tel: 6179 Cable: FORESTCOM. Librarian.

0017 Library, Woods and Forests Department. G.P Box 1604, Adelaide, South Australia 5001. 512402. Telex: AA 82231. Librarian.

0020 Tasmanian Forestry Commission Library. G.P Box 207B, Hobart, Tasmania 7001. Tel: 002-306 Librarian.

0021 Technical and Further Education. 41, Merri Street, South Brisbane, Queensland 4001. 2247411. W. Bowen.

Austria

0026 Generaldirektion der Oesterreichischen Bundesfor Bibliothek. Marxergasse 2, A-1030 Vienna. 0222-731531. Telex: 01-2575. Karl M. Heiden

Bangladesh

0028 Forest Research Institute. P.O. Box 273, Chittag Tel: 212164. Cable: FORESTRES, CHITTAGO Dr. M. Omar Ali, Director.

Belgium

0030 Bureau National de Documentation sur le Bois. Royale 109-111, 1000 Bruxelles. Tel: 02-219283

Brazil

0036 Biblioteca Central da Universidade Federa Vicosa. 36570, Vicosa, Minas Gerais. Tel: 8911

0037 Biblioteca Central do Instituto Brasileiro de De volvimento Florestal. Palacio do Desenvolvime 13 andar, Minsterio de Agricultura, Brasilia, Tel: 2550087 (PBX), ramais 126; 127. Telex: 1711. Bibliotecaria.

0039 Biblioteca Central, Universidade Federal Rura Pernambuco. Rua Manoel de Medeiros s/n Irmaos. Tel: 2685477, ramal 91. Maria Lucia donca Melo.

0040 Biblioteca Central, Universidade Federal Rura Rio de Janeiro. Km. 47 da Antiga Rodovia Rio Paulo, 23460 Seropedica, Rio de Janeiro. Seca Referencia e Intercamhio.

0043 Biblioteca do Instituto Nacional de Pequisa Amazonia. Caixa Postal 178, 69.000 Manaus, A zonia. Tel: 2341818, ramal 116. Telex: 269. Al Ferraz Suano da Silva.

0044 Biblioteca do Setor de Ciencias Agrarias. C Postal 672.80.000, Curitiba, Parana. Tel: 0 523422 ramal 20. Lea T. Belczak.

Centro de Documentacao da Madeira/Wood Documentation Centre. Caixa Postal 7141, 05508 Sao Paulo, S.P. Tel: 2682211, ramal 516. Telex: 011-22831; Cable: TECNINST. Marcio Augusto Rabelo Nahuz; Asa Fujino.

Centro do Documentacao e Informacao do INPA. Estrada do Aleixo, Km 3,5, Caixa Postal 478, 60.000 Manaus, Amazonia. Tel: 2326068; 2341815, ramal 116/117. Telex: (0922)269016/017; Cable: INAPA. Algenir Ferraz Suano da Silva; Ivonete Liberato da Silva.

Instituto de Pesquisas e Estudos Florestais, Biblioteca. Caixa Postal 9, 13.400 Piracicaba, Sao Paulo. Tel: 332080. Silvia Ap. Medeiros Rodrigues.

Servicio de Documentacao e Informacao, Faculdade de Ciencias Agrarias do Para. Caixa Postal 917, 66000 Belem, Para. Tel: 216-1110; 216-1310; 216-1510. Sandra Bordalla Robilotta.

Sistema Nacional de Informaca e Documentacao Agricola (SNIDA). Av. W/3 Norte, Quadra 515, Bloco C, 1 andar, Brasilia. Tel: 2733100, ramal 155. Telex: 061 1337. Yone Chastinet.

roon

Bibliotheque de L'Ecole Nationale Superieure Agronomique. B.P. 138, Yaounde. Tel: 224588. Zoue Ela Elie.

da

Alberta Energy and Natural Resources Library. Petroleum Plaza South Tower, 9915-108 Street, Edmonton, Alberta T5K 2C9. Tel: 403-4277425. Chief Librarian.

Bibliotheque Scientifique. Universite Laval, Quebec G1K 7P4. Tel: 6563478.

Bibliotheque, Centre de Recherches Forestieres des Laurentides. C.P. 3800, Ste. Foy, Prov. Quebec G1V 4C7. Tel: 418-6944428. Telex: 051-3765. Monique Kroon.

Departmental Library, Department of Fisheries and the Environment. Ottawa, Ontario K1A 1C7. Tel: 9971768. Telex: 053-3799. Miss Helen McCuaig.

Forestry Library, Faculty of Forestry, University of Toronto. Toronto, Ontario, M5S 1A1. Tel: 416-9786016. Librarian.

Library, Eastern Forest Products Laboratory. 800 Montreal Road, Ottawa, Ontario K16 325. Tel: 613-9939900, ext. 222. Librarian, Marjorie Wickens.

Library, Maritimes Forest Research Centre, Canadian Forestry Service. P.O. Box 4000, Fredericton, New Brunswick E3B 5P7. Tel: 506-4523541. Telex: 014-4615. Librarian or Information Officer.

Library, Ministry of Forests. Parliament Buildings, Victoria, British Columbia V8W 3E7. Tel: 3873628. S.E. Barker.

Library, Pacific Forest Research Centre, Canadian Forestry Service. 506 West Burnside Road, Victoria, British Columbia V82 1M5. Tel: 604-388311, ext. 146. Telex: 049-7177. Librarian, Alice Solyma.

0070 Macdonald College Library of McGill University. Barton Building, Macdonald College, Ste. Anne de Bellevue, P.Q. HOA ICO. Tel: 514-4572000. Telex: 05-821788. Miss Janet Finlayson.

0071 MacMillan Forestry/Agriculture Library. 2075 Wesbrook Mall, Vancouver, British Columbia V6T 1W5. Tel: 2283445; 2283609. Mary W. Macaree.

0073 Northern Forest Research Centre, Fisheries and Environment Canada. 5320-122d Street, Edmonton, Alberta T6H 355. Tel: 403-4357323; 403-4357324. David Robinson; Ron Pederson.

0074 Science Library, University of New Brunswick. Box 4400, Fredericton, New Brunswick E3B 5A3. Tel: 506-4533566; 506-4533567. Ms. M.J. Veach.

0075 Service de Bibliotheque et de Documentation du Complexe scientifique du Canada (SOBCS). 2700 Rue Einstein, Sainte-Foy, Quebec G1P 3W8. Tel: 418-6439730. Telex: 051-3324; TWX 610-571-5517. Pierre Bazinet.

0076 Technical Information Centre, Forest Fire Research Institute. 240 Bank Street, Ottawa, Ontario K1G 3Z6. Tel: 613-9960814. Telex: 053-3393. Thomas W. Miles, Information Officer.

0078 The Library, FORINTEK Canada Corp., 6620 N.W. Marine Drive, Vancouver, British Columbia V6T 1X2. Tel: 604-2243221, Local 216. Telex: 04-508552. Marion E. Johnson, Librarian.

Chile

0081 Biblioteca Area Ciencias Agropecuarias. Casilla 537, Concepcion. Tel: 22645, Anexo 265. Norma V. de Ramirez.

0082 Biblioteca Central de la Universidad Austral de Chile. Casilla 39A, Valdivia. Tel: 39112681. Anexo 290. Elisabeth Saelzer.

0084 Biblioteca Rector Ruy Barbosa. Casilla 9206, Santiago. Tel: 587042, Anexo 25. O. Carmen Perez.

0085 Biblioteca, Instituto Forestal. Huerfanos 554, Casilla 3085, Santiago. Tel: 36517. Teresa Munos P., Bibliotecaria.

0086 Centro de Ciencias Forestales, Universidad de Concepcion, Biblioteca. Casilla 537, Chillan. Tel: 22645. Sra Norma Valderrama Reyes.

0088 Facultad de Ingenieria Forestal. Casilla 567, Valdivia. Tel: 3911, Anexo 225. Telex: 71035. Dr. Renato Grez Z.

0089 Laboratorio Productos Forestales. Casilla 53-C, Concepcion. Tel: 24985, Anexo 63. Jefe Laboratorio.

Colombia

0090 Instituto de Investigaciones Forestales. Carrera 8, No. 40-78. Apartado Aereo No. 8668, Bogota. Tel: 2424706. Hector Rojas Leon.

0091 Servicio de Informacion y Documentacion Forestal (SEIDAL). Apartado Aereo 091676, Calle 84, No. 20-05, Bogota. Tel: 2361573; 2567370; 2567390. Jefe del Servicio: Angela de Caldas.

0092 Universidad del Valle, Departamento de Bibliotecas, Seccion de Documentacion. Apartado Aereo 2188, Cali. Tel: 591171, ext. 157. Cable: UNIVALLE. Clara Ines L. de Gonzales.

Congo

0093 Direction des Eaux et Forets et des Resources Naturelles. B.P. 98, Brazzaville. Tel: 812459. Directeur.

Costa Rica

0095 Centro de Informacion Tecnologica. Apartado 159, Cartago, Tel: 511122. Ing. G. Mirabelli.

0096 Centro Interamericano de Documentacion, Informacion y Comunicacion Agricola. Turrialba. Tel: 560022. Depto. Ciencias Forestales-Catie.

Czechoslovakia

0098 Documentation Centre of the Faculty of Forestry, Department of Scientific Information. Zemedelska 1, 662 65 Brno. Tel: 604. Ing. B. Horak.

0103 Vyskumny ustav lesneho hospodarstva—odborove informacne stredisko/Forest Research Institute. 960 92 Zvolen, Marxova 2175. Tel: 27311; 27312; 23397. Telex: 7284 VULHZ. C. Katarina Kobsvdobs.

Democratic Yemen

0104 Planning and Statistics Department. Ministry of Agriculture and Agrarian Reform, Aden. Tel: 22611. Cable: MINAGRIC ADEN. ANAL.

Ecuador

0108 Biblioteca Nacional. Sucre y Garcia Moreno, Quito. Tel: 212697. Sra. Mercedes Alvarez.

0109 Centro de Capacitacion e Investigacion Forestal "Luciano Andrade Marin." Conocoto, Provincia de Pichincha. Tel: 311092. Jefe del Centro Forestal de Conocoto.

0110 Facultad de Ciencias Agropecuarias. Apartado 'B', Loja. Tel: 961730. Dra. Elida Bertha Arias B.

El Salvador

0111 Biblioteca, Direccion General de Recursos Naturales Renovables. Apdo. Postal No. 2265, San Salvador. Tel: 270622. Personal de la Biblioteca.

Fiji

0112 Fiji Forest Department Library. Forest Department, Suva. Tel: 28151. A. Alston, Principal Utilization Officer.

Finland

0113 Forestry Library, University of Helsinki. Unioninkatu 40 B,00170 Helsinki 17. Tel: 1924236. Annikki Karjalainen.

0016 Oy Wilh. Schauman AB, Jakobstads Mills, Library. POB 42, 68601 Jakobstad. Tel: 67-10444421. Telex: 7514 WSJST SF. Mrs. Riita Grahn.

0019 Technical Information Service, Technical Research Centre of Finland. Vuorimiehentie 5 SF-02150 ESPOO 15. Tel: 35804561. Telex: 12-2972. Mr.
Laitinen, Director.

France

0123 Bibliotheque Nationale et Universitaire, Sectio
Sciences et Tecniques. 34, Bd. de la Victoire, S
bourg; B.P. 1037/F, 67070 Strasbourg Cedex.
88-613323. M.E. Geiss.

0127 Centre Technique Forestier Tropical (C.T.F.T.
bis Avenue de la Belle Gabrielle, 94130 Nogent
Marne. Tel: 8733295. Telex: c/o UPIEX 220429
Grasser.

0130 Documentation—Centre de Recherches Forest
d'Orleans. Ardon 45160 Olivet. Tel: 38-630206. T
INRAORL 760359 F. Mme. Garraud.

0131 Ecole Nationale du Genie Rural, des Eaux e
Forets. 14, Rue Girandet, 5402 Nancy Cedex.

0135 Service des Forets, Documentation. 1, Aven
Lowendal, 75007 Paris. Tel: 5559550. Mme. Le
son.

0137 Sous-Direction Documentation Information Et
85, Bd du Montparnasse, 75270 Paris Cedex 06
5559300, poste 41-44. Telex: STISI/202624F. N
Pruvot.

Germany, Federal Republic of

0141 Bibliothek der Forstlichen Fakultaet. Busgenw
D-3400 Goettingen. Tel: 0551-393407. Libra
Miss Christiane Kollmeyer.

Guatemala

0166 Centro Universitario del Nor Occidente (CU
ROC). Apartado Postal 68, Huehuetenango.
Edgar Rolando Barrios R.

Honduras

0170 Biblioteca "ESNACIFOR." No. 2, Siguatep
Comayagua. Tel: 732011; 732075. Cable: ESN
FOR, Siguatepeque, Comayagua, Honduras.

0171 Biblioteca del Centro Universitario Regiona
Litoral Atlantico (CURLA). Universidad Nac
Autonoma de Honduras, La Ceiba, Atlantida.
Victorina A. de Rivera.

0172 Sistema Bibliotecario. Ciudad Universitaria,
cigalpa. Tel: 2291017; exts. 122, 123, 124, 153,
Cable: BIBLIOTECA UNAH. Jefe de Servici
Publico.

Hungary

0173 Erdeszeti es Faipari Egyetem Kozponti Konyv
Pf. 132, H-9401 Sopron. Tel: 11100. Telex: 24
erdfa. Dr. Istvan Hiller, General Director o
Library.

0174 Forest Research Institute, Library. Frankel L
42-44, H-1023 Budapest. Tel: 150624; 351938
Kispeter Andrasne.

0177 Orszagos Muszaki Konyvtar es Dokument
Kozpont/Hungarian Central Technical Librar

Documentation Centre. P.O. Box 12, Reviczky u. 6, H-1428 Budapest. Tel: 336309. Telex: OMKDK H 22-4944.

A.P. Agricultural University Library and Documentation Centre. Hyderabad 500030. Tel: 48161. Cable: AGRIVARSITY. D.B. Eswara Reddy.

Documentation and Bibliography Section, Forest Research Institute. P.O. New Forest, Dehra Dun, 248006. Tel: 7021, ext. 45. Cable: Documentation FORESEARCH, Dehra Dun. N.K. Mathur, Senior Research Officer.

Kerala Forest Research Institute Library. Peechi 680653, Trichur, Kerala. Tel: Kannara—37. Librarian.

Library and Information Centre, Indian Plywood Industries Research Institute. P.O. Box 2273, Tumkur Road, Bangalore 560 022. Tel: 38231. Cable: IPIRI—Bangalore, India. Shri C.N. Deshprabhu.

esia

Library of the Forest Research Institute. P.O. Box 66, Bogor. Tel: 163. Cable: LPHUT. Mr. Rubardi.

Central Library and Documentation Center, Tehran University. Shahreza Avenue, Tehran. Tel: 6112842. Mr. Iraj Afshar.

Forestry and Range Organization, Tehran. Tel: 652102, 6. Public Relations and International Affairs Dep.

d

Forest and Wildlife Service, Department of Fisheries Library. Sidmonton Place, Bray, Co. Wicklow. Tel: 867751. Librarian.

y

Instituto di Selvicoltura. Via G. Amendola 165/A, 70100 Bari. Tel: 080-339761; 080-338769. Dr. Guiseppe Scarascia.

Servizio Documentazione, Instituto del Legno. 38010 San Michele all' Adige (Trento). Tel: 0461-63168. Telex: 40453 ILSMA. O. Delmarco; E. Cristellotti.

Faculty Library, Faculty of Agriculture, Nagoya University. Furo-Cho, Chikusa, Nagoya 464. Tel: 052-7815111. Ms. Michiko Iriyama, Staff Librarian.

Kyoto United Nations Depository Library. Kanden Building, Shiokoji-Shinmachi, Shimogyo-ku, Kyoto 600. Tel: 075-3718331. Mr. T. Hayashi.

Library, Wood Research Institute, Kyoto University. Uji, Kyoto. Tel: 0774-323111. Dr. Minoru Masuda, Library Committee.

National Diet Library. Nagata-Cho 1-10-1, Chiyoda-Ku, Tokyo 100. Tel: 03-5812331. Cable: NADLIB TOKYO. Y. Morita, Director, Division for Interlibrary Services.

0220 Technical Coordination Division, Forestry and Forest Products Research Institute. P.O. Box 2, Ushiku, Ibaraki 300-12. Tel: 02987-33211, ext. 291. Director.

Kenya

0222 Kabete Library, University of Nairobi. P.O. Box 29053, Kabete. Tel: 592191. Cable: UNIVET. Assistant Librarian.

Luxembourg

0227 Bibliotheque, Academie Internationale de Manternach. B.P. Wecker, Luxembourg Ville. Tel: 71480. Yvan Van Garsse.

Malaysia

0234 Reference and Information Division, Library, Universiti Sains Malaysia. Minden, Penang. Tel: 883882, ext. 390; 881331. Telex: USMLIB MA4054.

Mexico

0238 Centro de Documentacion Forestal. Apd. 37, Chapingo, Edo de Mexico. Tel: 5854555, ext. 245, 230. Luis Pinonsosa.

0239 Centro de Ensenanza, Documentacion e Investigacion de la Produccion y Transformacion de la Madera y Derivados—CEDIMA. P.O. Box 6-725, Guadalajara, Jalisco. Tel: 168806; 156987. Dr. Roman Lamas R.

0241 Instituto de Madera, Celulosa y Papel de la Universidad de Guadalajara. Apartado Postal 4-120, Guadalajara, Jal. Quim. Luz Elena Arce Castillo.

0242 Instituto Nacional de Investigacion y Capacitacion Forestales. Av. Progreso No. 5, Mexico 21, D.F. Tel: 5540422, ext. 142. Lic. Ma. de la Luz Vela Rosales.

Morocco

0244 Service Coordination, Synthese et Documentation. Direction des Eaux et Forets, Rabat, Chellah. Tel: 62565; 63946. Telex: 31696. Mr. Bendahman.

Netherlands

0246 Centre for Agricultural Publishing and Documentation (Pudoc). P.O. Box 4, 6700 AA Wageningen. Tel: 08370-19146. Telex: 45015; Cable: PUDOC, Wageningen. Dr. H.C. Molster.

0249 International Institute for Aerial Survey and Earth Sciences (ITC). P.O. Box 6, 7500 AA Enschede. Tel: 053-320330. Telex: 44525; Cable: AERSUR Enschede. J.H. ten Haken.

0250 Research Institute for Forestry and Landscape Planning De Dorschkamp. P.O. Box 23, 6700 AA Wageningen. Tel: 08370-19050. Cable: DORSCHKAMP WAGENINGEN. Ms. G.H. Jansen, Librarian.

0252 State Forest Service. Postbox 20020, Utrecht. Tel: 030-859111. Telex: 47542. Jr. M.G. Wagenaar Hummelinck.

New Zealand

0254 Library, Forest Research Institute. Private Bag, Rotorua. Tel: 82179. Cable: FRESTRA. Librarian.

0255 N.Z. Forest Products Ltd., Head Office Technical Library. Private Bag, Auckland. Tel: 592899. Telex: NZ 2411; Cable: PINEX. Mrs. L. Comfort, Head Office Librarian.

0256 New Zealand Forest Service Library. Private Bag, Wellington. Tel: 721569. Telex: N.Z. 31011; Cable: FORESTRY. The Librarian.

Nicaragua

0257 Banco Central de Nicaragua, Biblioteca y Servicios de Informacion. 2252-2253 Managua. Tel: 22751; 22851. Telex: BANCEDENIC 56. Seccion Servicios al Publico.

Nigeria

0259 Department of Forest Resources Management. University of Ibadan, Ibadan. Tel: 462550, ext. 1433; ext. 1437. Telex: CAMPUS 31128 IBADAN. Head of Department.

0260 Department of Forest Resources Management Library. University of Ibadan, Ibadan. Tel: 62550/1433. Departmental Librarian.

0261 Forestry Research Institute of Nigeria Library. P.M.B. 5054, Ibadan. Tel: 24721/218. Telex: 31207; Cable: FORSEARCH. Principal Librarian.

Norway

0264 Library of the Agricultural University of Norway. N-1432, As-NLH. Telex: 17125 nlhbi. Astrid Alfnes.

0266 Norsk Treteknisk Institut/The Norwegian Institute of Woodworking and Wood Technology. Box 337, Blindern, N-Oslo 3. Tel: 02-469880. Mr. Bjoern Moerk.

Papua New Guinea

0269 Papua New Guinea Office of Forests. P.O. Box 5055, Boroko. Tel: 254022. Cable: FORESTS. Chief Research Officer.

Peru

0270 Biblioteca Agricola Nacional. Apartado 456, Lima. Tel: 352035. Ruth Ivazeta de Barnett.

0271 Centro de Documentacion de la Direccion General Forestal y de Fauna. Zv. Sta. Cruz 734, Jesus Maria, Lima. Tel: 235833. Genny Alberca Vivanco.

0272 Departamento Academico de Forestales. Apartado 77, Universidad Nacional del Centro del Peru. Tel: 232392. Jefe del Departamento Academico de Forestales.

Philippines

0275 College of Forestry Library. College, Laguna 3720. Tel: 3440. The Librarian.

0279 Tarlac College of Agriculture Library. Camiling, Tarlac 2111. Chief, Library Services.

Poland

0282 Scientific Technical and Patent Information Ser
in the Field of Wood Science and Technology
Winiarska 1, 60-654 Poznan. Tel: 46001. T
0415506 ITEDE. Dr. Aleksander Kisielewski.

Romania

0290 Biblioteca Centrala a Universitatii Brasov. Bdul.
Gheorghiu-Dej 9, 2200 Brasov. Tel: 44401. Servi
Documentation.

Rwanda

0291 Bibliotheque de l'Universite National du Rwa
B.P. 54, Butare. Tel: 271 (ligne exterieure U
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sarbeten. Drottninggatan 97, S-11360 Stockh
Tel: 08-241920. Ingemar Nordanst.

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0390 North Central Forest Experiment Station, Library. 1992 Folwell Avenue, St. Paul, Minnesota. Tel: 612-6450841, ext. 257. Floyd L. Henderson.

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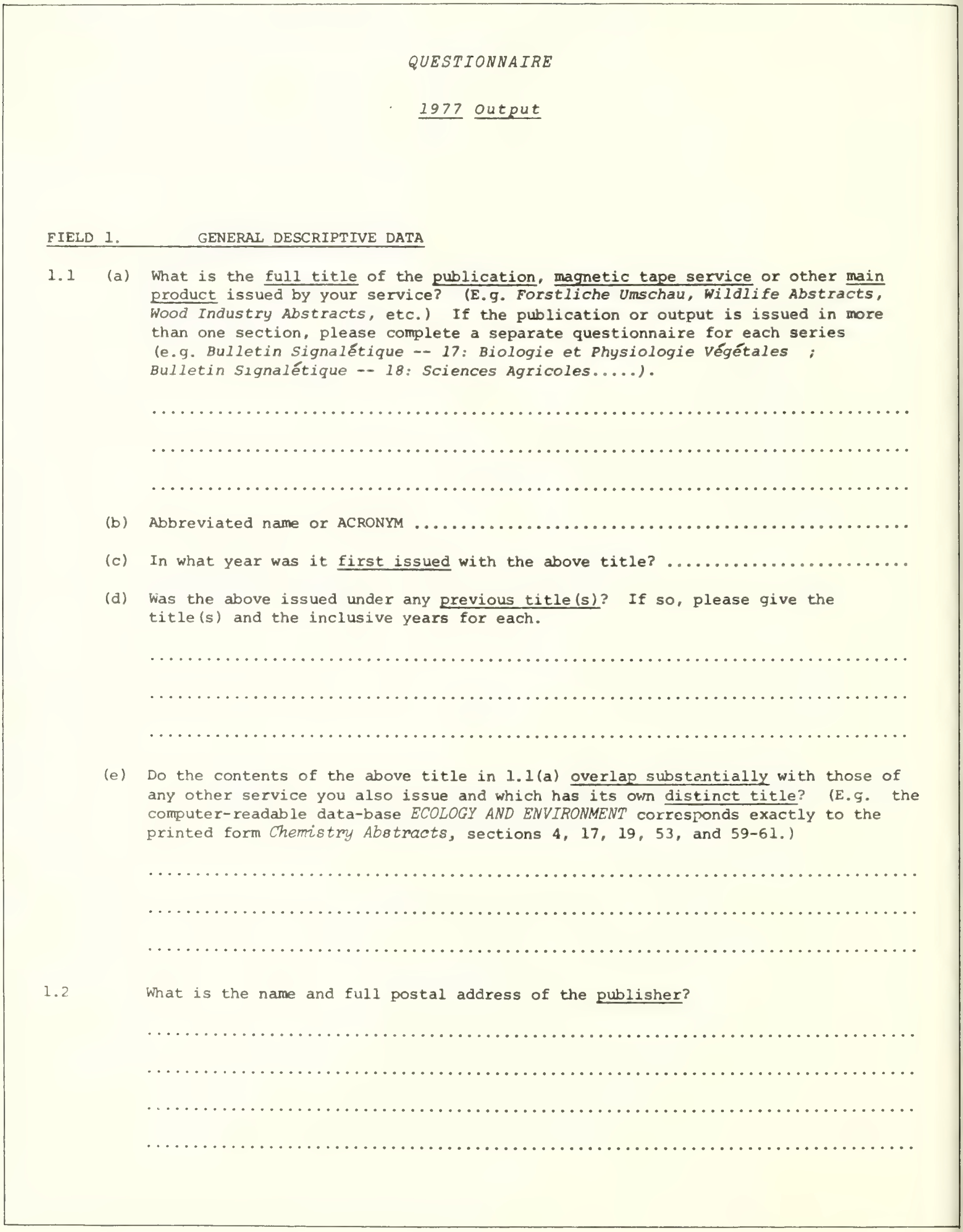
0420 Indok Sluzba za Boldarstvo/Indoc Service for Forestry; Indok Sluzba za Lesarstvo/Indoc Service for Wood Technology. P.O. Box 486, Vecna Pot 30, 61001 Ljubljana. Tel: 061-264761. Marija Zorn; Dusan Robic; Marjeta Gorsic; Niko Torelli.

Zaire

0424 Bibliotheque Centrale, Universite Nationale du Zaire. Campus de Kisangani, B.P. 2012, Kisangani. Tel: 3007. Telex: 19. Lelo Mamosi, Bibliothecaire en Chef.

B. Questionnaire

This questionnaire was mailed to approximately 300 producers of documentation services of potential interest to forestry, or forest products, or both. In addition to English, French and Spanish versions were used appropriate. The response to this questionnaire pro the data for all but eight (marked with an asterisk) entries in this directory.



QUESTIONNAIRE

1977 Output

FIELD 1. GENERAL DESCRIPTIVE DATA

1.1 (a) What is the full title of the publication, magnetic tape service or other main product issued by your service? (E.g. *Forstliche Umschau, Wildlife Abstracts, Wood Industry Abstracts*, etc.) If the publication or output is issued in more than one section, please complete a separate questionnaire for each series (e.g. *Bulletin Signalétique -- 17: Biologie et Physiologie Végétales ; Bulletin Signalétique -- 18: Sciences Agricoles.....)*.

....

....

....

(b) Abbreviated name or ACRONYM ....

(c) In what year was it first issued with the above title? ....

(d) Was the above issued under any previous title(s)? If so, please give the title(s) and the inclusive years for each.

....

....

....

(e) Do the contents of the above title in 1.1(a) overlap substantially with those of any other service you also issue and which has its own distinct title? (E.g. the computer-readable data-base *ECOLOGY AND ENVIRONMENT* corresponds exactly to the printed form *Chemistry Abstracts*, sections 4, 17, 19, 53, and 59-61.)

....

....

....

1.2 What is the name and full postal address of the publisher?

....

....

....

....

1.3 Issuing organization

What is the name and full postal address of the organization responsible for compiling and distributing this service (if different from 1.2)?

....

....

....

....

1.3.1 How is the issuing organization financed?

☐ by a government
☐ by a university
☐ by a professional or industrial association
☐ as a commercial enterprise
☐ by an international organization (e.g. FAO)
☐ by a private foundation
☐ other (please specify) ....

1.3.2 The issuing organization belongs :
☐ to one country only.
☐ to two or more countries.
☐ to a regional or international organization.

Name the country/countries/organization ....

....

....

1.4 If the service has an associated library or documentation center, what is its name and full postal address?

....

....

....

....

1.5 What type of organization(s) or group(s) of individuals would find your service helpful?

....

....

FIELD 2. INPUT

2.1 Source of citations

(a) Are all the citations derived from the primary (i.e. original) literature? ☐ YES ☐ NO

(b) How many different journals are regularly scanned for input? ....

(c) How many secondary sources (other abstract journals, bibliographic title services, etc.) are regularly scanned for input? ....

(d) ☐ A list of the publications scanned is available.

(e) Sources of data-base citations are approximately of the following percentages :

......% Journal articles

......% Monographs, dissertations, theses

......% Government documents & reports

......% Conference papers (either from published proceedings or preprints)

......% Manufacturers' catalogs

......% Patents

......% Secondary sources

......% Other

2.2 Coverage

2.2.1 *Geographic coverage*

(a) ☐ The service covers the primary literature about all areas of the world.

(b) ☐ Geographic coverage is limited to the primary literature :

☐ on a specific region.

☐ on a group of countries.

☐ on one country.

Name the country/countries/region : ....

....

....

2.2.2 *Coverage by languages*

(a) ☐ The primary literature of forestry, forest products, and/or related fields for almost all languages is covered.

(b) ☐ Only the following languages are ☐ COVERED or ☐ EXCLUDED :

....

....

....

2.2.3 *Coverage by subject*

(a) The subject coverage includes :

☐ forestry and forest products.
☐ forestry alone.
☐ forest products alone.
☐ specific subject areas (shown in 2.2.3(c) below).

(b) What was the number of abstracts and of cited titles produced in 1977?

ABSTRACTS	CITED TITLES

(c) What was the approximate number of abstracts and/or cited titles produced in each of the following subject areas in 1977?

FORESTRY	Abstracts	Cited titles
Forest ecology (including climate, animal habitat, water-soil-root relations, etc.)		
Silviculture (including genetics)		
Forest management (including mensuration, harvesting, land-use planning)		
Forest economics (including taxation, land ownership, stand evaluation)		
Insects, diseases and damage (other than fire)		
Fire		
Range management		
Game, wildlife and fish management		
Recreation		

FOREST PRODUCTS	Abstracts	Cited titles
Physical and mechanical properties of wood (including strength tests, standards)	☐	☐
Wood chemistry (including extractives)	☐	☐
Milling and machining of lumber	☐	☐
Veneer; Plywood; Composite boards (including particleboard, hardboard, adhesion and adhesives)	☐	☐
Pulp and paper	☐	☐
Preservation; Seasoning	☐	☐
Wood as a source of energy	☐	☐
Marketing of forest products	☐	☐

2.2.4 *Data base (card file, magnetic tape, etc.)*

(a) Do you compile more citations than you actually publish or otherwise issue? ☐ Yes ☐ No

(b) If so, what is the total number of citations you compiled in 1977? ....

(c) What is the cumulative number of citations in your data base up to and including 1977?

....

FIELD 3. DATA HANDLING METHODS

Which method of data handling do you use?

☐ Manual (includes vertical cards, peek-a-boo cards, manually sorted cards, etc.)

☐ Mechanical (paper tapes, machine-punched cards, etc.)

☐ Computerized (electronic data processing)

FIELD 4. OUTPUT

4.1 Output data

Does the output consist of:

☐ Title citations only (i.e. bibliographic references) ?

☐ Title citations plus keywords?

☐ Title citations plus informative or indicative abstracts?

4.2 Language(s) of titles

Are the document titles given in:

☐ The original language(s) only?

☐ In translation only? Specify translation language(s) ....

....

☐ In both the original language(s) and in translation? Specify translation language(s) :

....

4.3 Language(s) of abstracts

If abstracts are published or otherwise issued, specify the language(s) in which they are written :

....

4.4 Arrangement

(a) The output is arranged by :

☐ subject

☐ titles of the documents

☐ author

☐ titles of primary journals or sources scanned

☐ other arrangement (please specify) ....

4.5 Indexes

4.5.1 *Author index*

(a) ☐ An author index is published every .... months.

(b) ☐ A cumulative author index is published every ☐ .... months.
☐ .... years.

4.5.2 *Subject index*

(a) ☐ A subject index is published every .... months.

(b) ☐ A cumulative subject index is published every ☐ .... months.
☐ .... years.

(c) What is the average number of subject index terms per citation? ....

(d) ☐ A controlled vocabulary (thesaurus) is used.
If so, is it available for examination? ☐ YES ☐ NO

(e) The following type of subject indexing is used :

☐ Conventional alphabetical
☐ KWOC (Keyword-out-of-context)
☐ KWIC (Keyword-in-context)
☐ Other (please specify) ....

4.5.3 *Geographical index*

☐ A geographical index is published every ☐ .... months.
☐ .... years.

4.5.4 *Other indexes*

If other types of indexes (e.g. taxonomic) are issued, please specify ....
....
....

4.6 Output form, price and frequency

4.6.1 *Output form*

In which of the following forms is the output available?

☐ Journal
☐ Computer print-out
☐ Manually sorted punched cards
☐ Punched tapes
☐ Other (please specify) ....
☐ Card service
☐ Microforms (Microfilm, microfiche, etc.)
☐ Machine punched cards
☐ Magnetic tapes

4.6.2 *Annual price and frequency*

Please give below the annual price and frequency of issue for each output form checked in 4.6.1.

4.6.21 Type of form (please specify) ....

(a) This form is issued : ☐ irregularly.
☐ every ...... week(s).
☐ every ...... month(s).

(b) The annual price for this form is :

In country of issue (in its own currency) ....
In country of issue (in $ U.S.) ....
Outside issuing country (in its currency) ....
Outside issuing country (in $ U.S.) ....

4.6.22 Type of form (please specify) ....

(a) This form is issued : ☐ irregularly.
☐ every ...... week(s).
☐ every ...... month(s).

(b) The annual price for this form is :

In country of issue (in its own currency) ....
In country of issue (in $ U.S.) ....
Outside issuing country (in its currency) ....
Outside issuing country (in $ U.S.) ....

IF MORE THAN TWO FORMS ARE AVAILABLE, PLEASE PUT THE ABOVE INFORMATION FOR THOSE FORMS ON A SEPARATE SHEET OF PAPER AND ATTACH AT THE END OF THIS QUESTIONNAIRE; PLEASE NUMBER THE INFORMATION --- 4.6.2.

4.6.3 *Bibliographic record elements of output*

Each bibliographic record of the output contains the following elements, whenever applicable to the citation :

☐ Record number
☐ Personal author(s)
☐ Corporate author(s)
☐ Original title
☐ Translated title
☐ Report or patent number
☐ Series and/or journal title(s)
☐ Serial volume/issue reference
☐ Place of publication
☐ Publisher
☐ Date of publication
☐ Indication of item source or item type (jnl., monog., govt. doc...)
☐ Collation (pagination, illustr., etc.)
☐ Conference title
☐ Source available
☐ Price of item, when known
☐ Keywords
☐ Abstract
☐ Digest
☐ Subject headings
☐ Author(s)' address(es)
☐ CODEN
☐ ISSN
☐ ISBN
☐ Geographic location of subject material
☐ Other (please specify) ....
....

4.7 Additional services

What additional services are provided from the data-base?

☐ SDI (Selective dissemination of information)
☐ Retrospective retrieval searches
☐ Other services (please specify) ....

4.8 Back-up services

(a) In addition to your principal output, what other non-data-base services do you provide?

☐ Full size copies of original documents
☐ Microcopies of original documents
☐ Library loans of original documents
☐ Translations of original documents
☐ Other services (please specify) ....
....

4.8 (b) If a translation service is provided, please specify from which language(s) and into which language(s) :

From .... Into ....

From .... Into ....

From .... Into ....

From .... Into ....

We would very much appreciate it if you would send us any brochures or other descriptive literature that you have telling about your service.

PLEASE ATTACH ADDITIONAL NOTES, COMMENTS OR INFORMATION
BELOW OR ON SEPARATE SHEETS OF PAPER

and

please remember to include the number
of the section referred to.

THANK YOU!

Evans, Peter A., and Gary L. Skupa, compilers.
1981. **International directory of documentation services concerning forestry and forest products**. Gen. Tech. Rep. PSW-47, 71 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

This directory lists 120 documentation services concerned with forestry, forest products, or related fields in 28 countries. The entry for each service includes title of service, cost, publisher, subject coverage, formatting data, input sources, indexing and data-handling methods, and availability of special services other than the primary ones of indexing and abstracting.

Retrieval Terms: indexing services, abstracting services, documentation services, forestry—indexing and abstracting, forest products—indexing and abstracting.

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Proceedings of the Symposium on

Isozymes of North American Forest Trees and Forest Insects

July 27, 1979, Berkeley, California

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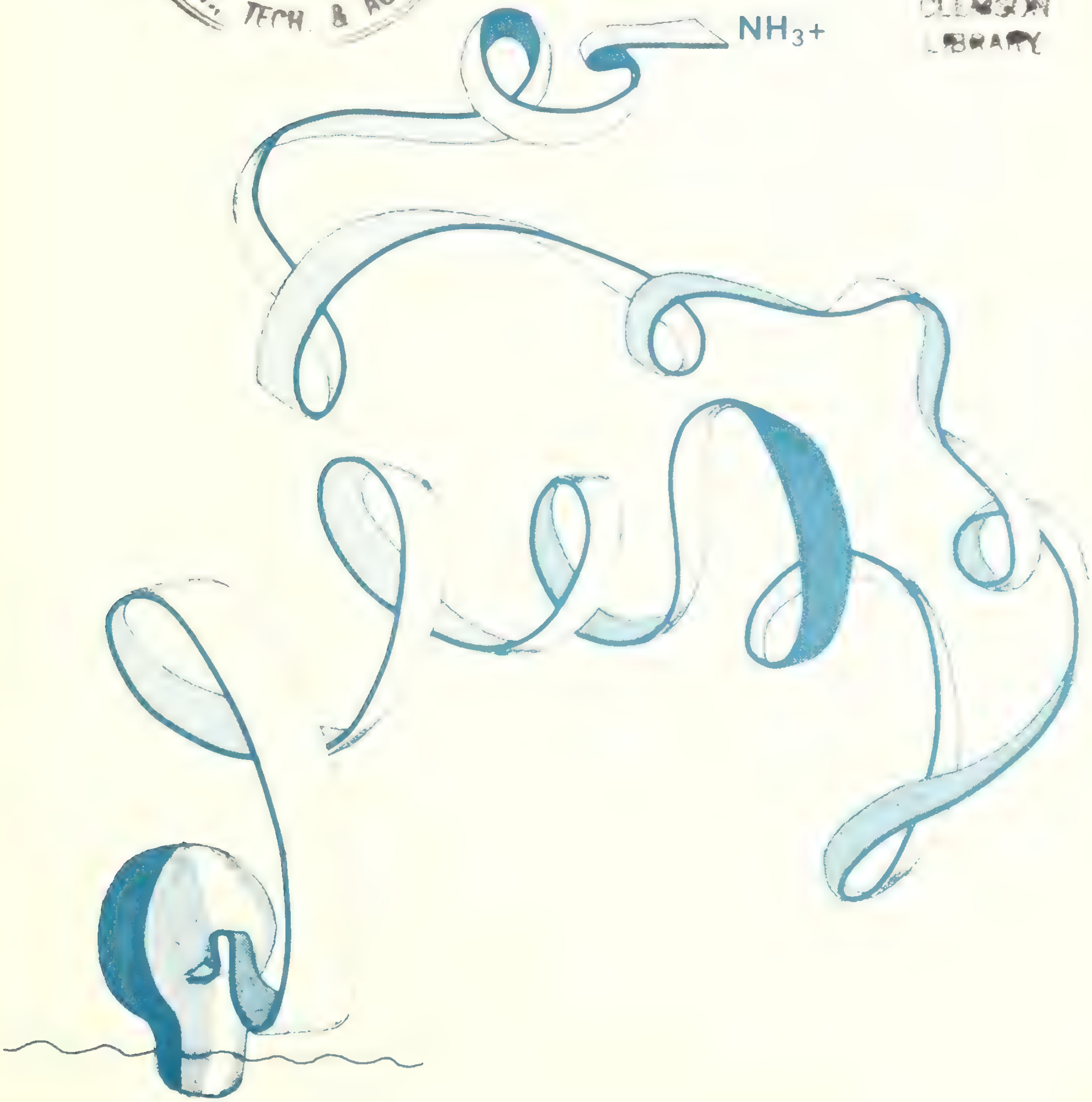

Technical Coordinator:

M. THOMPSON CONKLE, a geneticist, works in the Genetics of Western Forest Trees Research Unit, with headquarters in Berkeley, California, and field facilities at the Institute of Forest Genetics, in Placerville, California. He earned a bachelor's degree (1959) in forestry at Michigan State University, East Lansing, a master's degree (1962) in forest genetics at North Carolina State University, Raleigh, and a doctorate (1976) in forestry and genetics at the University of California, Berkeley. He joined the Station's research staff in 1965.

Cover: The polypeptide strand forming will become an enzyme. A ribosome translates genetic information as it moves along a messenger-RNA molecule.

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

April 1981

oceedings of the Symposium on

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ly 27, 1979, Berkeley, California

. Thompson Conkle
chnical Coordinator

CONTENTS

Isozymes and the Genetic Resources of Forest Trees 1
A. H. D. Brown and G. F. Moran
Isozyme Variation and Linkage in Six Conifer Species 11
M. Thompson Conkle
Analysis of Mating System Parameters and Population Structure in Douglas-fir Using Single-locus and Multilocus Methods 18
D. V. Shaw and R. W. Allard
Isozyme Studies of Forest Insect Populations 23
Molly W. Stock
Associations Between Heterozygosity and Growth Rate Variables in Three Western Forest Trees 27
Jeffry B. Mitton, Peggy Knowles, Kareen B. Sturgeon, Yan B. Linhart, and Martha Davis
Levels of Genetic Variation in Trees: Influence of life history characteristics 35
J. L. Hamrick, J. B. Mitton, and Y. B. Linhart
Genetic Structure of Populations and Differentiation in Forest Trees 42
Raymond P. Guries and F. Thomas Ledig
Analyses of Gene Diversity in Some Species of Conifers 48
Francis C. Yeh
An Analysis of Genetic Architecture in Populations of Ponderosa Pine 53
Yan B. Linhart, Jeffry B. Mitton, Kareen B. Sturgeon, and Martha L. Davis
Applying Isozyme Analyses in Tree-Breeding Programs 60
W. T. Adams

PREFACE

Isozyme techniques are currently the best means for evaluating the genetic structure of forest populations. Data from isozyme studies can help researchers evaluate, sample, and conserve the genetic variation of forest tree species. Our perception of genetic variation in forest populations has been significantly enlarged by new findings from studies detecting enzyme alleles of numerous genes of forest trees and insects.

The 1979 meeting of the Western Forest Genetics Association in Berkeley, California, provided an opportunity for a symposium, on July 27, to present some of these findings. It was appropriate to hold the symposium in conjunction with the Western Forest Genetics Association meeting, since most researchers of isozymes of North American forest organisms work in Western North America. The symposium was sponsored by the Pacific Southwest Forest and Range Experiment Station's Institute of Forest Genetics, which maintains a center for isozyme research in population genetics of forest trees.

The gathering of researchers and their presentations attested to the high value and multiple uses of isozyme technology for resolving genetic variation in forest organisms. Participants reported the distribution of genetic variation between and within several species, and proposed strategies for maintaining the variation through future generations. The population structure of species was evaluated at several levels—from broad regional comparisons to groups of trees on mountain slopes.

For many years, growth tests coupled with quantitative analyses of forest trees have estimated the proportion of total phenotypic variation that is attributable to genetic causes. But almost all the observed variation in isozymes stems from genetic differences: species and populations can be compared on the basis of the amount of genetic variation each possesses. The amount of genetic variation, whether considering an entire species or a small group of trees, is measured by the average heterozygosity of numerous loci. Presentations in the proceedings give information that relates average heterozygosities to growth rates and to life history characteristics of trees.

The relationship between a host tree and its pests adds another dimension to the study of forest genetics. Both the trees and the pests can differ in the genetic structure of their respective populations and in the amount of genetic variation each possesses. One presentation in this symposium points to the importance of the genetic variation of insects in designing effective pest management strategies.

Forest trees generally are difficult to work with in genetic studies because of their large sizes and slow developmental rates. One feature of conifers, however, elevates their value in isozyme studies. The female gametophyte tissue—the endosperm of conifer seeds—and its egg cells develop from a single haploid nucleus; mature seeds contain a haploid gametophyte and a diploid embryo. The genes segregating among the gametophytes of a tree permit direct genetic tests of allelism. One presentation in the proceedings uses segregation from multiple loci to determine linkage relationships. Others analyze the gametophytes and accompanying embryos from individual seeds to determine the seed tree and pollen parent genotypes. The proportion of outcrossing and selfing are evaluated for open-pollinated seed. Knowledge of the seed tree genotype and of pollen parentage are shown to be valuable for a variety of uses in tree breeding programs.

In all, an impressive diversity of information is represented in the papers of this symposium. It is obvious that a technology that yields precise genetic information for numerous genes, with great efficiency of time and space and at relatively low cost, will be a great aid in tree improvement and gene conservation.

We, at the Pacific Southwest Forest and Range Experiment Station in Berkeley, were delighted with the enthusiasm of our friends and colleagues who attended the symposium and prepared papers for these proceedings. To each participant, we extend our warmest appreciation for current, advanced information of the highest quality. Their successful efforts in resolving genetic variation in forest organisms will undoubtedly stimulate new work in forest genetics and greatly assist in the wise management of genetic resources.

We extend appreciation to the Western Forest Genetics Association for publicizing the symposium and providing local arrangements. Special thanks are due Ray Steinhoff, 1979 Chairman of the Western Forest Genetics Association, and William B. Critchfield and William J. Libby, co-chairmen of the 1979 meeting of the Association.

M. Thompson Conkle
Forest Service, U.S. Department of Agriculture
Technical Coordinator

Isozymes and the Genetic Resources of Forest Trees[1]

A. H. D. Brown[2] and G. F. Moran[3]

Abstract: Genetic data are an essential prerequisite for analysing the genetic structure of tree populations. The isozyme technique is the best currently available method for obtaining such data. Despite several shortcomings, isozyme data directly evaluate the genetic resources of forest trees, and can thus be used to monitor and manipulate these resources. For example, preliminary isozyme data indicate that domestication of cultivated species has generally reduced variation within populations. Geographic differences among natural populations are less evident in trees than in herbaceous plants, but need to be considered in sampling and conservation strategies. In dealing with remnant population size (N_r) and distribution, management programs should recognize that the half-life of heterozygosity is about 1.4 N_r generations, whereas the number of trees required to retain half the current alleles after a bottleneck is about the square root of the original population size.

The growing awareness of two major theses provide the occasion of this opening contribution to the mposium. The first is that the genetic resources of onomic plant species, and in particular of forest trees ecies, are finite. Yet, these resources have been managed ithout concern for their conservation or renewal. It is ow clear that our remaining forest resources must be used udently to guarantee a long future for managed species. ne second thesis is that the isozyme technique is well ited for monitoring and assisting the manipulation of our netic heritage, at least in part (Brown 1978). The last cade has witnessed the growth and impact of this chnique in population biology. The ensuing contribuons to this symposium will amply demonstrate the ways which electrophoretic data can contribute to our genetic owledge of populations of forest trees.

This paper first considers the properties of isozyme data d then discusses how the data can be used to monitor and nserve the genetic resources of forest trees.

SOZYMES: BONANZA OR BLIND ALLEY N FOREST GENETICS?

henotypic as Opposed to Genetic valuation

Two radically different approaches can be taken when easuring differences among individuals, populations or ecies. The first we define as the "phenotypic" approach. is motivated by the argument that it deals directly with aracters of economic or biological importance. The ideal this approach is to know the phenotypic expression of yield, quality, and pest and disease resistance in all possible environments. Clearly, this ideal is unattainable, because the need for decisions limits, in space and time, the number of environments that may be tested. Quantitative genetics attempts to overcome these limitations by using a predictive model. The model assumes that unspecified polygenes can simulate the genetic and developmental complexities that underly phenotypic measurements and their variation. Various classes of effects on phenotypic variation—additive, dominance, epistasis, genotype × environment interaction—are defined (Libby and others 1969). The predictive power, however, is severely limited to the genotypes tested, the environments experienced, and the mode of measurement. Of course phenotypic (agronomic or silvicultural) assessment and phenotypic selection are essential in any plant breeding program. It is less certain whether such data provide valid measures of genetic variation and genetic similarity among populations.

The second approach to evaluation, the "genetic" approach, is entirely different in emphasis. Its aim is to detect genetic differences as close as possible to the DNA (deoxyribonucleic acid) level. The ideal of this approach is to know all the DNA sequences. Such basic data would form direct measures of how genetically variable is one population, and how similar it is to another, entirely free of environmental effects. Data from different species would be directly comparable. Again, this ideal is far from being a reality. Perhaps it may be attainable for very restricted classes of DNA (for example, organellar DNA, highly repeated DNA) or in very simple organisms (Smith 1979). But the need for "genetic," as distinct from "phenotypic," evaluation is apparent.

Because we cannot presently measure variation directly at the DNA level, we must lay down criteria for the choice of techniques that are currently feasible. *Table 1* summarizes four criteria first suggested by Hubby and Lewontin (1966; see also Lewontin 1974). These criteria require that the effect of an allelic substitution at a locus be detectable (C), and distinguishable from the substitution of any other allele at the same locus (A), or other loci (B).

---

[1] Presented at the Symposium on Isozymes of North American Forest ees and Forest Insects, July 27, 1979, Berkeley, Calif.

[2] Principal Research Scientist, Commonwealth Scientific and Industrial search Organization (CSIRO), Division of Plant Industry, Canberra, istralia.

[3] Experimental Officer, CSIRO, Division of Forest Research, nberra, Australia.

Table 1–*The Hubby-Lewontin criteria for genetic markers, and the properties and pitfalls of the isozyme technique with respect to each criterion*

Criteria to be met	Properties of isozymes	Problems occurring
A. Alleles are distinct in individuals	Codominance; free of epistatic or environmental effects	Genetic or environmental mobility; mobility modification
B. Effects are locus-specific	Enzyme specificity	Nonspecific assays; duplication or polyploid
C. All substitutions are detectable	Charge-state separation, irrespective of function or variation	Detectable class of base substitutions is restricted and biased in variation
D. Loci are sampled randomly	Assay availability is independent of variation	Loci assayed are a limited class and differ in variation

Further, the sample of loci studied should be random, irrespective of function, or likely level of polymorphism (D).

The Isozyme Method

As perceived by Hubby and Lewontin (1966), the isozyme technique meets these criteria more closely than any preexisting method. Its general properties relevant to the criteria are also listed (*table 1*). In short, one can study discrete Mendelian genes. This applies even in long-lived organisms such as trees, because individual seeds or seedlings can be assayed as members of progeny arrays.

An additional and important advantage of the method is the facility with which an array of enzymatic loci can be assayed using material in minute quantities, and with minimal preparation. The isozyme technique, therefore, represents the best currently available method for measuring genetic variation, close to the DNA level, relatively free of environmental effects, and on a manageable number of samples.

Pitfalls and Shortcomings of Isozyme Data

Some of the problems of isozymes associated with each of the Hubby-Lewontin criteria are listed in *table 1*. First mention is of some known cases where simple Mendelian codominant inheritance does not apply. Post-translational modification, either genetic (Law 1967) or environmental (Cullis 1977) in origin, is a possibililty of which isozyme geneticists are becoming increasingly aware. The best way to avoid this pitfall is to verify by a Mendelian analysis that a set of isozyme variants are *allozymes*, that is, they are coded by alleles at a locus. This is especially the case for enzymes which do not form heteromultimers, or which are assayed nonspecifically (for example, esterases), or which are known to be affected by environment (for example, peroxidases).

Enzyme assays vary in their specificity. Diploid barley has at least 10 genetically defined esterase loci (Hvid and Nielsen 1977). With such nonspecific enzyme assays, a Mendelian analysis is essential. Duplication of genetic material, as in polyploidy, can often lead to the inability to ascribe a particular variant to a single locus. Special chromosomal stocks, such as nullisomics (Hart and Langston 1977) or haploids, if available, provide a definitive solution to this problem. This problem is rare in forest species, however, as diploidy is the common condition (Libby and others 1969).

With respect to the third criterion, two problems arise. The first is that electrophoresis does not detect all single base substitutions. About 23 percent of substitutions are synonymous and do not alter the amino acid because of redundancy in the code. About 67 percent of amino acid replacements do not alter net charge (Marshall and Brown 1975b). Some fraction of these replacements may be detectable by more refined electrophoretic techniques, or by altered heat sensitivity of the enzyme. Also, apparently long sequences of DNA inserted within the coding sequence of many eukaryotic genes may or may not be removed in the production of mRNA (messenger ribonucleic acid) (Crick 1979). These sequences are not translated, and are thus beyond the reach of electrophoretic surveys. Their function is not known, but preliminary evidence suggests that they can be quite variable. Crick (1979) describes the discovery of inserted sequences and split genes as "a mini-revolution in molecular genetics".

The other problem with respect to the third criterion is that, given access to a restricted class of base substitutions at a locus, can we assume that this class is unbiased with respect to the level of overall variability? Unfortunately, mounting evidence indicates that we cannot. For example, careful hybridization studies of variation in the DNA of sea urchins reveal a remarkably high level—4 percent—of base pair mismatching among individuals (Britten and others 1978). This mismatching is computed to be an order of magnitude greater than that predicted from electrophoretic heterozygosity, even after the latter has been corrected for synonymy and electrophoretically silent amino acid replacements. Isozymes are not so "close to the gene level" after all.

The fourth criterion raises the same two questions, but with respect to the loci sampled. Electrophoresis is used to study variation in the structural region of nuclear genes for certain restricted classes of proteins. Several studies of variation at these loci, either within functional classes of enzymes (Johnson 1974), or in relation to their physical parameters (Koehn and Eanes 1978), indicate that such loci differ in their tendency to vary genetically. This point must be taken into account in comparative studies of data on different species from different laboratories that may not have covered comparable sets of loci. Leigh Brown and Langley (1979) have suggested that the enzymes typically studied may overestimate genetic variation. They found narkedly less variation (4 percent heterozygosity in bout 54 of the abundant proteins of adult *Drosophila*) nan that predicted from allozyme studies (14 percent). Also, he inability of comparative electrophoretic divergence to easure evolutionary morphological divergence has been tressed by Wilson and others (1977). The lack of nformation on eukaryotic regulation systems and devel- pmental sequences, and of data on sequence variation in egulatory loci or variation in their chromosomal location re severe shortcomings. Fortunately, the future applica- on of other techniques of molecular biology to popula- on studies does offer the hope of complementing the ozyme picture. These techniques include restriction uclease analysis of organellar DNA's (Scowcroft[4]), DNA ybridization (Hall and others 1976), and ultimately loning of specific sequences and DNA sequencing, and haracterization of highly repeated classes of DNA for eir base sequences and chromosomal location.

A major shortcoming—perhaps the greatest of all—is at the adaptive or selective significance of the bulk of llozyme variation remains obscure (Lewontin 1974). Is is variation adaptive or is it "evolutionary noise"? A less soteric way of framing this question is to ask whether the enes studied by isozyme techniques have any relation at ll to the characters of interest to the plant breeder. Is the udy of allozyme variation a blind alley for forest tree reeding? Preliminary studies have shown it is possible to amine this question with a combination of population, hysiological, and biochemical approaches. For example, cohol dehydrogenase polymorphism in certain plant ecies shows population differentiation, selection re- onses, adaptive differences in tolerance to waterlogging, nd in germination rates, and parallel variation in enzyme tivity (Brown 1979). Much more evidence must be sembled, however, before a general answer is possible.

OREST TREES AND THEIR GENETIC ESOURCES

The genetic resources of forest tree species consist of oth primary and secondary gene pools (Frankel 1977). he primary reservoirs are those of undisturbed natural rests; the secondary sources include the remaining trees ter ecosystem disturbance or harvesting, and the produc- ve populations planted from local or exotic seed. Many thors have reviewed the genetic research on forest trees om the standpoint either of utilization or of genetic nservation (Libby and others 1969, Richardson 1970, tern and Roche 1974). We now outline some issues in the atus, handling, and conservation of genetic resources, hich arise from the distinctive features of forest trees, in ntrast to crop plants.

Size and Individuality

As large organisms, forest trees can readily be the target of individual phenotypic selection for growth of timber quality characteristics. This facility raises the question of the role of individual selection when collecting reproductive material. Should seed be taken only from a limited number of outstanding or "plus" trees? To answer this question, we first consider natural stands and ask whether the sampling is for conservation or breeding. Is the goal to obtain the largest amount of potentially useful genetic variation from that population; or is it to select a limited number of trees as parents in a seed orchard or breeding program? If the goal is *conservation*, Marshall and Brown[5] (1975a) have argued against sampling biased by phenotype. The sampling pattern at a site should be random with respect to phenotype, but representative with respect to ecological variation within the site. *Where* a plant grows is, perhaps, as reliable a guide as *what* it looks like when we consider its likely contribution to the genetic resources of the species. If the sampling aim is restricted to *breeding*, then the collection of seed from "plus" trees is debatable. It is difficult, however, to avoid unwanted biases from, for example, ephemeral selection criteria, diverse age structure of the population, and physical or biotic microenvironmental effects. If the "plus" trees are to be propagated clonally, one may have more justification for selection. In plantations, with a uniform age structure, and more random distribution of genotypes is microenvironments, it is usually easier to designate "plus" trees. Still, they could amount to a random sample. Most important, however, is the *number* of trees sampled. This number should not be restricted solely on the grounds that few of the available trees are outstanding. Genetic data that show the effect of biased as opposed to random sampling in tree populations are obviously needed.

A second practical consequence of tree size contrasts with the situation in most crop and forage species. The culture of a single plant uses considerable resources, and severely limits the population numbers in seed orchards, and *ex situ* conserved stands (Bouvarel 1970).

Longevity

As long-lived plants, the phenotypes of mature forest trees sum up a long history of environmental variation in space and time. This fact raises the issue of genic variation and fitness. Is genic variation maintained by heterozygote advantage in most environments? This may or may not mean that heterozygotes show less phenotypic plasticity for certain morphological traits (Bradshaw 1965). Or, are the individual alleles at polymorphic loci adapted to cope with different environments? Testing for isozyme-environment associations must take account of this complex of possibilities and of conflicting predictions from different modes of selection.

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[4] Scowcroft, W. R. Nucleotide polymorphism in chloroplast DNA of *cotiana debneyi*. Theor. Appl. Genet. (In press.)

[5] Marshall, D. R. and A. H. D. Brown. Theory of forage plant collection. *In* Genetic Resources in Forage Plants. R.A. Bray and J.G. McIver, eds. CSIRO, Melbourne (In press).

Longevity and the delay in maturity in forest species, compared with annual crops, raise a practical issue in conservation by seed storage (Wang 1975). The viability of stored seed can approach the duration of the life cycle. If so, it must be regenerated as often as it takes to grow one crop of seed. Stored seed has an important role in the distribution of genetic resources without repeated collecting. What, then, is its role in genetic conservation of trees? Stern and Roche (1974) view *in situ* conservation as an interim measure until conservation is possible by "other means." In contrast, it can be argued that seed storage is essentially a provisional measure until *ex situ* stands are established, or a temporary insurance against the accidental destruction of *in situ* stands or plantations. The role of seed storage is severely limited in the case of tropical species with "recalcitrant" seeds.

Fecundity

The number of seeds produced by a single tree, even in one crop, may be enormous. This high fecundity enables tree species to tolerate high genetic loads and therefore, high levels of heterozygosity. From the standpoint of seed collection, this is one reason why the number of seeds sampled per mature individual can and should be much greater in trees than in crop or pasture species. Another reason is that the subsequent multiplication in plantations of any seed sample from trees is a slow and costly process. More specific recommendations on sample size are given below.

Outcrossing

Almost all the forest trees in which the breeding system has been studied are outbreeders. From this we can infer that heterozygosity is beneficial. A corollary is that inbreeding depression is likely to be evident in progeny if selfing rates are high. Further, the evidence suggests that outbreeders have less scope for the evolution of coadapted complexes of genes (at least in the sense of genes in linkage disequilibrium) than inbreeders (Brown 1979). Because of maternal heterozygosity and outcrossing, the seed crop on an individual tree is genetically heterogeneous (in contrast to inbred crops).

Harvesting

The link between economic utilization and the threat to genetic resources in forest species is more direct and final than in most other economic species. Logging destroys the individual as a genetic resource, and renewal requires reforestation based on sound genecological principles.

Stage of Domestication

Forest trees are wild plants at the earliest stages of domestication (Libby 1973). The time scale of the domestication process will be long. Unless the use of vegetative propagation becomes widespread, breeding and agronomic advances in themselves will not be the major causes of genetic erosion, as they are in agricultural crop species. The chief threat to agricultural genetic resources is the replacement of the older, more variable strains with modern advanced cultivars. The principal task in their conservation is the collection and preservation in gene resource centers, of the dwindling stocks of land races (Frankel 1974). The major threats to the integrity or, indeed, the survival of the genetic resources of forest trees are (a) ecosystem destruction and changing patterns of land use, (b) widespread planting with a few fast-growing species, (c) selective harvest of trees, and (d) plantation or reforestation practices based on limited or maladapted germplasm. Several case histories of tropical pines, teak, eucalypts, and others were reviewed at the Third World Consultation on Forest Tree Breeding, Canberra, 1977. The desirability and need for *in situ* conservation was frequently stressed.

With these general features of forest trees as a background, we now return to considering the importance of population genetic research based on the isozyme technique.

ISOZYME STUDIES AND GENE RESOURCE MANAGEMENT IN FOREST TREES

What are the roles that genetic evaluation based upon the isozyme technique might play in the management of the genetic resources of forest species (Feret and Bergmann 1976)? We would like to stress two interrelated functions—monitoring and decisionmaking.

Isozymes are ideal for monitoring:

(a) the current level of genetic variability in populations of economic species. This would furnish a base-line for evaluating the genetic consequences of any practice, as well as furnishing data for comparing levels of variability in different species (Hamrick and others 1979);

(b) increased genetic vulnerability in plantations as indicated by a decline in variability because of selection;

(c) loss of variation resulting from ecosystem destruction;

(d) the extent of divergence and variation in heterozygosity between natural populations of a species;

(e) the differentiation within a species between natural and planted populations, especially in other countries where exotic species (for example *Pinus radiata* D. Don, *Eucalyptus grandis* W. Hill ex Maiden) may have undergone adaptive "naturalization" (Frankel 1977);

(f) the extent of effective cross-pollination in seed orchards;

(g) pollen contamination of seed orchards;

) pollen contamination of *in situ* reserves by plantations;

) the inbreeding load in severely bottlenecked populations, such as those that regenerate from decimated stands following clear felling;

) seed and clone identification.

Several of these topics will be discussed in this mposium. As an example, we quote some of our own and her results to illustrate the impact of domestication on vels of genetic diversity. *Table 2* gives estimates of genetic versity (H) (Nei 1975), and alleles per locus (A) in four ses. The statistic H is the mean expected panmictic terozygosity ($H = 1 - \Sigma p_i^2$, where p_i is the frequency of the h allele). In barley (Hordeum), the sequence wild ogenitor → primitive varieties or land races → advanced ltivars shows a fall in genetic variation both within lines d in the total sample. In contrast, domestication in *hlox* is accompanied by increased total diversity. This crease probably arose from the deliberate collection and ntinual use of interesting variants. Darwin described an alogous consequence of artificial selection in the mestication of pigeons. In forest trees, the preliminary ta indicate important changes in diversity levels with anagement, especially in *P. radiata*.

Recently, Hamrick and others (1979) have concluded m an analysis of published data that trees are genetically ore variable on the average than herbaceous plants, cause they are widespread, long-lived, large, fecund, and tcrossing species. This conclusion differs from that of imal data (Powell 1975, Nevo 1978): many vertebrates ve less than one-half the heterozygosity of invertebrates. Is ngevity or size of an organism (the attribute that Frankel d Soulé[6] use as an index of conservation strategies) a nflicting indicator of genetic variability in plants as compared with animals? Perhaps the plant literature is limited and biased by studies of inbreeding, colonizing, exotic annuals on the one hand, and the genecological studies of forest trees on the other. Several of these latter studies, including ours on mating systems, deliberately focused *only* on variable loci.

Table 3 summarizes some estimates of population genic diversity per variable locus ($\bar{H}$) and population differentiation ($D_{ST}/\bar{H}$, where $D_{ST}=H_T-\bar{H}$ [Nei 1975]) in tree species. These estimates are compared with the same statistics in inbreeding and outbreeding herbaceous plants. As a group, the wind-pollinated conifers show the least degree of population differentiation. Trees pollinated by insects or birds show about three times as much, and are comparable with herbaceous outbreeders. *Eucalyptus caesia* Benth., a bird-pollinated, and geographically restricted species shows the highest differentiation of these trees, approaching the level for inbreeding herbs. Clearly, a wide range of population structures is found in trees.

DECISIONS

We will now outline some issues in which management decisions could be made with more precision if extensive isozyme data were available.

Sampling Strategies

How large should samples be and how should they be disposed among trees and among populations? Answers to this question depend on the purpose of sampling. This may be (a) to assemble the genetic resources in a target area for direct use, breeding or conservation; (b) to measure population genetic structure at individual loci, or obtain a sample that faithfully reflects gene frequencies; (c) to

Table 2–*Comparative genetic diversity (H) and alleles per locus (A) of domesticated lines and related natural populations*

Species	Lines	Allozyme loci[1]	Within lines A	Within lines H	Total A	Total H_T	Source[2]
Hordeum vulgare	32 Scandinavian varieties	11[1]	1.02	0.007	1.55	0.127	a
	Composite cross XXI, F_{17}	17[1]	–	–	1.53	.094	b
	11 Iran land races	17	1.21	.072	1.94	.180	c
H. spontaneum	28 Israel populations	17[1]	1.56	.109	4.12	.216	b
Phlox drummondii	16 Cultivars	17	1.12	.041	1.41	.133	d
	10 Populations	17	1.25	.063	1.29	.089	d
Pinus sylvestris	2 Seed orchards	3	3.5	.36	3.7	.37	e
	3 Sweden populations	3[1]	4.3	.33	5.3	.38	d
Pinus radiata	1 Seed orchard (30 clones)	18[1]	–	–	1.67	.118	f
	20 Breeding clones	19	–	–	1.74	.145	f
	5 California populations	19	1.84	.139	2.63	.161	f

[1] *Loci:* More loci are in the original source, but only comparable loci are included here.

[2] *Sources:* (a) Almgard and Landegren (1974), (b) Nevo, E., D. Zohary, A. H. D. Brown, and M. Haber, 1979. Genetic diversity and environmental associations of wild barley, *Hordeum spontaneum* in Israel. Evolution. (In press.) (c) Brown (unpublished). (d) See Brown (1979) for references, (e) Rudin and Lindgren (1977), (f) Moran (unpublished).

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[6] Frankel, O. H. and M. Soulé. Conservation and evolution. lanuscript in preparation.)

Table 3–*Population genic diversity per variable locus ($\bar{H}$) and differentiation ($D_{ST}/\bar{H}$) in trees*

Species	Variable loci	Populations	$\bar{H}$	$D_{ST}/\bar{H}$ Percent	Source[1]
Abies lasiocarpa	1	3	0.40	3.0	(a)
Picea abies	4	8	.42	4.5	(a)
P. abies	6	10	.40	4.7	(a)
P. abies	4	8	.35	2.4	(a)
P. abies	10	4	.41	2.9	(b)
P. engelmannii	1	3	.47	12	(a)
Pinus longaeva	11	5	.47	3.6	(c)
P. nigra clusiana	3	7	.48	13	(d)
laricio	4	12	.30	6.9	(d)
nigricans	3	11	.52	12	(d)
pallasiana	4	10	.30	7.0	(d)
P. radiata	19	5	.14	15	(e)
P. rigida	15	4	.17	1.1	(b)
P. sylvestris	3	3	.33	14	(a)
P. virginiana	2	4	.29	2.6	(g)
Pseudotsuga menziesii	2	6	.55	3.0	(h)
P. menziesii	4	9	.59	2.9	(i)
Eucalyptus caesia	8	10	0.11	78	(j)
E. cloeziana	5	17	.25	17	(k)
E. delegatensis	4	8	.34	24	(a)
E. obliqua	3	7	.39	21	(a)
E. pauciflora	7	3	.28	2.2	(a)
Ficus carica	2	4	.53	2.3	(a)

	Summary		Average		Weighted[2]	Average
			$\bar{H}$	$D_{ST}/\bar{H}$[3]	$\bar{H}$	$D_{ST}/\bar{H}$
Outbreeders	Wind-pollinated trees		0.372	7.4	0.298	6.8
	Animal-pollinated trees		.317	16	.265	20
	Herbaceous	(b)	.325	22	.282	18
Inbreeders		(b)	.126	118	.133	102

[1] *Source:* (a) see Brown (1979) for references, (b) Lundkvist (1979), (c) Hiebert, see Hamrick and others (1979), (d) Bonnet-Masimbert and Bikay-Bikay (1978), (e) Moran (unpublished), (f) Guries and Ledig (1977), (g) Witter and Feret (1978), (h) Mejnartowicz (1976), (i) Yang and others (1977), (j) Moran and Hopper (unpublished), (k) Turnbull (unpublished).

[2] Weighted by the number of variable loci in each study.

[3] Computed by dividing the sum of D_{ST} estimates by the sum of H estimates.

measure multilocus associations; or (d) to estimate parameters of the mating system.

Sampling for the first purpose has been discussed extensively by Marshall and Brown[5] (1975a). The key to this sampling is to maximize the number of *locally common* alleles in a collection whose total size is strictly limited. Locally common alleles are defined here as alleles that assume a frequency greater than 0.10 in only one locality. Alleles with two such occurrences are termed sporadically common. The existence of locally common alleles in plant populations is discussed elsewhere (Brown 1978). The limited data from forest species (*table 4*) indicate that of all alleles detected, locally common alleles make up a lesser (but significant) fraction, compared with herbaceous plants. Our rule of thumb has been to sample about 50 plants at random and visit as many contrasting sites as possible. If this is difficult or time consuming, then samples of fewer plants from more sites should be taken (Marshall and Brown[5]).

In forest trees, this rule applies directly to the sampling of vegetative material. For seed samples, however, it requires variation because of the high fecundity, the outbreeding system, and the difficulty of sampling each additional tree. Samples from fewer trees (n), but more seed per tree (k), such that nk > 100 are in order. In practice, however, much larger samples than this are taken in forestry to allow for seed requests, and to avoid early resampling or regeneration.

Samples for research, or for the representation of site allele frequencies, must be based on a reasonable number of trees. A minimum value for n follows from the limiting formula for the variance of allele frequencies in the seed generation (Brown and others 1975) with large k and assuming p = q = 0.5

$$\lim_{k \to \infty} \sigma_p^2 = (1 + 3F)^2/32n(1 + F)$$

Table 4–*The number of alleles with various kinds of distribution*

Species	Populations	Loci	Kinds of enzymes	Common alleles Widespread	Common alleles Sporadic	Common alleles Localized	Rare alleles Widespread	Rare alleles Localized
Picea abies	11	4	4	10	1	1	1	1
P. abies	10	6	4	12		2	3	1
P. abies	4	11	6	19	3	3	16	13
Pinus longeava	5	14	7	27	3		3	—
P. nigra clusiana	7	4	1	9	3	1	1	—
laricio	12	4	1	8	1	–	1	1
nigricans	11	4	1	10	—	-	2	1
pallasiana	10	4	1	7	—	1	1	3
P. radiata	5	19	13	26	1	3	10	10
P. rigida	4	15	10	19	2	1	8	—
Pseudotsuga menziesii	6	2	1	7	—	-	4	1
P. menziesii	9	4	3	12	—	–	—	—
Eucalyptus caesia	10	8	6	12	1	6	—	2
E. cloeziana	17[1]	5	5	9	3	1	1	—
E. delegatensis	8	4	4	8	1		1	
E. obliqua	7	3	3	6		2	4	2
Summary				Percentage of variants				
Wind-pollinated trees		91	—	41	8	7	27	17
Animal-pollinated trees		20	—	39	13	23	75	10
Wild herbaceous (8 entries[2])		14	—	31	18	28	7	16
Cultivars (4 entries[2])		25		45	14	23	4	14

[1] These populations were grouped into seven geographic regions.

[2] From Brown (1978). See *table 3* for sources of remaining data.

vhere F is the inbreeding coefficient.

The minimum number of trees required to ensure that he difference (d), between the sample allele frequency and ts true population frequency, is exceeded on less than 5 ercent of occasions is

$$n = (1 + 3F)^2/8(1 + F)d^2$$

$$\simeq 0.2\ d^{-2},\ \text{assuming}\ F < 0.10$$

or d = 0.1, we would require large samples from at least n = 0 trees. A sample of 10 trees from each of two populations an detect differences in gene frequency between them of .2 at the 5 percent level of significance.

Much larger samples are needed to detect weak multi-ocus associations in the adult generation (Brown 1975). inally, sampling for the study of mating systems unfor-unately is ideally served by one contrary principle: the ampling of trees from within the same microenvironment nd in close proximity (Brown and others 1975). Other-vise, microgeographic differentiation can lead to inflated stimates of self-fertilization. In general, more information n allelic frequency patterns could be used to assess ptimal sampling strategies within and among sites.

Iarvesting in Naturally Regenerating Systems

What and where to log and what to leave? Selective arvesting followed by natural or assisted reforestation is a common practice. There are important genetical issues for which we have little genetic data to inform us. If size or growth rate is related to heterozygosity, will selective logging amount to selection against heterozygotes and, therefore, lead to destabilized genetic equilibria (Charlesworth 1972) and the loss of certain polymorphic alleles? Dysgenic selection could also arise in an additive model, simply by removing the preferred alleles. Perhaps it would be a better strategy, genetically, to clear fell most of the area and leave certain areas untouched as a seed source. A major variable here would be the pattern and scale of microdifferentiation. For example, the study of Mitton and others (1977) of *Pinus ponderosa* Dougl. ex Laws., indicates that reserved areas should be located on both north- and south-facing slopes, and that of Bergmann (1978) of *Picea abies* K. indicates that elevational gradients are important.

Critical Population Sizes for Conservation

How large a population should be set aside and managed as a long-term source of genetic diversity (conservation *in situ*)?

As the need for conservation becomes more pressing, ecologists and geneticists are being asked to recommend the minimum size of a viable population. As yet there is no single answer to this question. Frankel and Soulé[6] have suggested 50 for the basic irreducible number for conservation genetics. They regard this number as the absolute minimum below which inbreeding ($\Delta F = 1 - (1/2N)$) would be unacceptably greater than 1 percent per generation. Of course, we refer to *effective* population number—actual numbers being somewhat larger. This reasoning, however, does not apply to inbreeding or to apomictic plants. Furthermore, populations of this size have little scope for adaptive evolution, a prerequisite for long-term survival. Franklin (see Frankel and Soulé[6]) has proposed the population size of 500, so that the effects of drift would be negligible when compared with those of selection of measurable intensity.

Latter and Frankel (in Frankel 1970) have suggested using the equilibrium formula of Crow and Kimura (1970) which is

$$H_e = 4Nu/(1 + 4Nu) = \theta/(1 + \theta)$$

in which

H_e = equilibrium heterozygosity
N = effective population number
u = mutation rate
$\theta = 4Nu$

If we assume $H_e = 0.3$ and $u = 2 \times 10^{-6}$ (Mukai and Cockerham 1977), both figures for electrophoretically detectable mutation, we obtain the number, $N \simeq 50{,}000$. This is the effective number required to prevent neutral heterozygosity declining at all from its present level. Thus, we have a range of answers (from 50 to 50,000) based on a range of rationales. The answer will vary for different species, so that no rationale is universally applicable.

Another way to look at this issue is to introduce the time element into the calculations, and ask what is *the half-life of heterozygosity* in generations, given a particular effective size? The loss of one-half the heterozygosity is biologically equivalent to one round of complete selfing.

Let t_j denote the time in generations required for the current heterozygosity (H_o) to fall to a value j H_o ($o < j < 1$) in a restricted population of effective size $N_r u$ and neutral mutation rate u. If $H_e = 4N_r u/(1 + 4N_r u)$, the new equilibrium heterozygosity, and assuming [$j H_o > H_e$], the number of generations is

$$t_j = \frac{\log_e \left\{[j H_o - H_e]/[H_o - H_e]\right\}}{\log_e \left\{1 - 2u - 1/(2N_r)\right\}}$$

In particular, the half-life of heterozygosity is approximately

$$t_{0.5} \simeq 1.4\, N_r$$

If we assume that the "time scale of concern" (Frankel 1974) for forest species is of the order of 100 generations or 1000 years (Frankel and Soulé[6]), and that we wish to **preserve at least one-half the heterozygosity by that date, the effective number required is $N_r = 70$.**

The loss of heterozygosity is but one dimension to the problem of population size. A second and potentially more important problem is the numbers of alleles lost in a bottleneck. We may again ask an analogous question.

If the original population size is N_o, what size of relic population, N_r, is required to retain half the alleles currently present? We can use the sampling theory for neutral alleles (Ewens 1972) to attempt an answer to this question. We will assume two values for $\theta = 4N_o u$, namely $\theta = 0.5$ or 1.0. In this section, u denotes the *total* mutation rate.

In the population, the actual number of alleles is

$$n_a = \theta \int_{1/2N_o}^{1} (1-x)^{\theta-1} x^{-1}\, dx$$

$$\text{For } \theta = 1, \qquad n_a|\theta{=}1 = \log_e(2N_o)$$

$$\text{and for } \theta = 0.5, \qquad n_a|\theta{=}0.5 \simeq [\log_e(8N_o)]/2$$

From Ewens (1972), the expected number of alleles retained in the sample (the relic population) is

$$n_r = \sum_{i=1}^{2N_r} \frac{\theta}{\theta + i - 1}$$

Using an integral approximation, this summation can be evaluated as

$$n_r \cong \theta \left\{ \log_e [(\theta + 2N_r - 1)/\theta] \right\} + 0.5$$

We wish to find the values of N_r which will yield $n_r/n_a = 0.5$, to retain half the alleles.

For $\theta = 1$; $N_r = 0.43(N_o)^{1/2}$, and for $\theta = 0.5$;

$N_r = 0.26(N_o)^{1/2}$

Unfortunately, rather large standard errors are associated with the number of alleles per locus retained in a relic population. Applying the same approximation procedure to Ewens' (1972) variance formula, we obtain for the variance,

$$\text{var}\,(n_r) \simeq \theta \left\{ \log_e [(\theta + 2N_r - 1)/\theta] - 1 \right\}$$

However, if one considers that a large number of independent loci ($v > 100$) are polymorphic in the population, it is possible to ask what is the number required to ensure survival of one-half of all the alleles with 95 percent certainty. For $\theta = 1$, the effective population size (N_r) required for this is

$$N_r \simeq 0.43 N_o^{1/2} \text{ x } \exp\, [2\{\log_e(0.1N_o)\}/v]^{1/2}$$

Original population size (N_0)	Number of polymorphic loci (v)		
	100	1000	∞
10,000	62	48	43
100,000	209	158	136

These figures indicate that, as a rough guide, the number to retain to ensure one-half the alleles survive with 95 percent certainty is about the square root of the original population size. More precise calculations would be possible when more estimates of θ, u and v are available.

Population Distribution

Should only one large population be set aside, or is it sounder genetically to divide the requirements into several partially isolated subpopulations?

If s is the number of subpopulations, each of effective size N_s, and m is the migration rate between them in the island model (Nei 1975), the total heterozygosity maintained in the whole ensemble (H_T) is

$$H_T = 1 - [1+u\{s/m+4sN_s\}]^{-1}$$

From this formula, it can be seen that H_T will increase under subdivision as $s/m + 4sN_s$ increases. The island model of migration is the most conservative from this viewpoint. The quantity sN_s nominally equals N_r, the total number retained from the original population. This quantity, however, is not likely to remain constant with increasing s; rather, it will decline because of the need for buffer zones around each subpopulation. More and more subpopulations of smaller size may render each one steadily more vulnerable, so that the total (N_r) declines as s increases. The requirement that the quantity (s/m) increase with increasing s means that, as the number of subpopulations and hence their proximity increases, a less than commensurate proportional increase in migration will occur between them. The optimum value of s to maximize H_T could be defined if we had information on buffer-zone requirements and on gene flow with increasing s.

CONCLUSIONS

The isozyme technique is a quantum jump forward in research on the genetics of forest trees. It does more than ust measure another set of characteristics, because it enables a direct genetic evaluation of the status of genetic resources. Despite the real limitations of isozyme data, which may in the near future be partly met by the application of newer molecular techniques in population studies, it is possible to make decisions on the manipulation and conservation of these resources, aided by such data. An isozyme laboratory may be considered demanding of personnel and financial resources. Yet these costs should be compared with those of establishing and maintaining large-scale field trials at several sites for several years. It is our view that genetic evaluation is as essential a component as phenotypic evaluation in research programs aimed at supporting decisions on the management of the genetic resources of forest trees.

Preliminary isozyme studies in several cultivated plants (for example, barley, tomatoes, *Phlox*, radiata pine), have quantified the impact of domestication on genetic variation. The erosion of genetic resources and, hence, the greater genetic vulnerability of planted populations, is evident. Comparative studies of variation patterns in trees and herbaceous plants emphasize the diversity of population genetic structures in plants. The degree of geographic differentiation among populations is more limited in trees than in herbs, but nonetheless significantly affects sampling and conservation strategies. Estimates of present day heterozygosity, mutation rates, gene flow, and differentiation permit an objective approach to questions of remnant population size and distribution. Several recommendations of minimum populations size may be compared within practical and species-specific constraints. Effective population sizes of about 70 allow one-half the current heterozygosity to remain after 100 generations, whereas the number of trees required to ensure with 95 percent certainty that one-half the current alleles survive the bottleneck is approximately the square root of the current population size. As further isozyme data accrue, more precise estimates and strategies will be possible.

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Isozyme Variation and Linkage in Six Conifer Species[1]

M. Thompson Conkle[2]

Abstract: Isozymes of female gametophyte tissue were analyzed for allelic variation in knobcone, lodgepole, loblolly, Jeffrey, and sugar pines and in Douglas-fir. Linkage was studied in the five pines. The average number of alleles and average herozygosity per enzyme locus were estimated. Knobcone pine ranked lowest among the six species in number of alleles and average heterozygosity; loblolly pine and Douglas-fir ranked highest. Numerous linkages were identified, and one chromosome segment contained between one-fourth and one-third of all loci examined. Linked loci had a consistent gene order in the different pine species. Linkage relationships support the concept that similar isozymes represent the same loci in each pine species. The consistency with which loci map in the same order and with similar map distances in species from different subsections of the genus, further suggests that evolution of the pines is not associated with major chromosome rearrangements.

The analysis of genetic variation in forest trees entered a new phase with the application of electrophoresis to etect allelic differences at isozyme loci. Gametophytes om seed of single trees provide excellent material for ssessing isozyme variation. Enzymes are analyzed at the ist-germinated stage of development, and diploid enotypes of parent trees are inferred from the segregation f allele phenotypes of the haploid female gametophytes. eed from some of the heterozygous parent trees are nalyzed in large numbers to determine if enzyme variants gregate according to simple Mendelian ratios. A one-to-ne segregation ratio of phenotypic variants is evidence for lelism. Homozygous loci within a single tree are lentified without error and the samples per tree are ufficient to minimize the misclassification of heterozygous ci.

This paper reports a two-stage analysis. In the first stage, e amount of genetic variation in several species of two onifer genera was estimated. Gametophytes from seed of dividual trees were analyzed for segregation and data ere obtained on the number of alleles and the average eterozygosity per locus. The six species compared were ouglas-fir and five North American pines. In the second age, linkage from segregation in female gametophytes of eterozygous trees was estimated. Linkage data are rovided for the five pine species.

SOZYME VARIATION

The six conifers in this study were knobcone pine (*Pinus tenuata* Lemm.), lodgepole pine (*P. contorta* Dougl. ex oud.), loblolly pine (*P. taeda* L.), Jeffrey pine (*P. jeffreyi* rev. & Balf.), sugar pine (*P. lambertiana* Dougl.), and Douglas-fir (*Pseudotsuga menziessi* [Mirb.] Franco). The geographic origins and numbers per species are listed in *table 1*. Sugar pine is classed within the subsection *Strobi* in the subgenus *Strobus* (the white pines). Within the subgenus *Pinus* (the hard pines), loblolly pine is within the subsection *Australes*, Jeffrey pine is in the subsection *Ponderosae*, lodgepole pine is within the subsection *Contortae*, and knobcone pine is in the subsection *Oocarpae*.

The minimum sample size was six gametophytes per tree and heterozygous loci were only misclassified when all six gametophytes carried one allele or its alternate, a probability of $2X\ (1/2)^6$, or 0.03. Standard laboratory techniques for starch gel electrophoresis provided information for 21 enzyme systems (*table 2*) and as many as 43 loci per gametophyte.

While analyzing the loci of these species, some general observations concerning gene phenotypes became obvious:

- The number of zones that developed bands within a particular enzyme system was consistent for different species. That is, if an enzyme system resolved only one zone of activity for a particular species, it resolved a single zone of activity for the the other species.
- The relative mobilities of bands within enzyme systems were similar for different species. For example, if an enzyme system of one species had two zones of activity, two zones were also found in other species and the bands had identical or nearly identical mobilities.
- The characteristic isozyme banding phenotypes for different loci were consistent among different species. For example, band phenotypes for a particular locus were very dark staining and wide, and a second locus had band phenotypes that were light staining and narrow. These two loci had similar appearances in different species and genera. The number, mobility, and appearances of primary bands, and the characteristics of nearby secondary bands—whether leading, trailing, or in multimeric combinations—were constant for the conifer species I analyzed.

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[1] Presented at the Symposium on Isozymes of North American Forest ees and Forest Insects, July 27, 1979, Berkeley, Calif.

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Table 1–*Species, geographic origin, and number of trees in the enzyme analyses*

Species	Stands	Geographic origin	Trees
Knobcone pine (*Pinus attenuata* Lemm.)	10	Range wide	49
Lodgepole pine (*P. contorta* Dougl. ex Loud.)	1	Sierra Nevada, California	40
Loblolly pine (*P. taeda* L.)			
Natural stand	1	Schenck Forest, Raleigh, North Carolina	146
Superior trees	(Sample)	Throughout Southeastern U.S. sample of trees from the North Carolina State Tree Improvement Program	90
Jeffrey pine (*P. jeffreyi* Grev. & Balf.)	4	Central Sierra Nevada, Sierra Nevada, California	75
Sugar pine (*P. lambertiana* Dougl.)	(Sample)	Rangewide in California	58
Douglas-fir (*Pseudotsuga menziesii* [Mirb.]Franco)	1	Cascades, west-central Oregon	152

Table 2–*Enzyme systems analyzed from conifer gametophytes*

Isozyme	Abbrev.	Enzyme Commission Code	Reference
Acid phosphatase	ACPH	3.1.3.2	Scandalios 1969
Aconitase	ACO	4.2.1.3	Yeh and O'Malley[1]
Alcohol dehydrogenase	ADH	1.1.1.1	Scandalios 1969
Aldolase	ALD	4.1.2.13	Yeh and O'Malley[1]
Catalase	CAT	1.11.1.6	Scandalios 1969
Diaphorase	DIA	1.6.4.3	Yeh and O'Malley[1]
Esterase (colorimetric)	EST	3.1.1.2	Scandalios 1969
Esterase (florescent)	FLEST	3.1.1.2	Mitton and others 1979
Glutamate dehydrogenase	GDH	1.4.1.2	Shaw and Koehn 1968
Glutamate oxalacetic transaminase	GOT	2.6.1.1	Brewbaker and others 1968
Glucose-6-phosphate dehydrogenase	G6PD	1.1.149	Shaw and Prasad 1970
Isocitrate dehydrogenase	IDH	1.1.1.42	Nichols and Ruddle 1973
Malic dehydrogenase	MDH	1.1.1.37	Nichols and Ruddle 1973
Peptidases			
Leucine-amino peptidase	LAP	3.4.11.1	Scandalios 1969
Alanine-amino peptidase	ALAP	3.4.11.1	Ott and Scandalios 1978
Peptidase	PEP	3.4.13.11	Nichols and Ruddle 1973
Peroxidase	PER	1.11.1.7	Shaw and Prasad 1970
6-Phospho-gluconate dehydrogenase	6PGD	1.1.144	Brewer 1970
Phosphoglucose isomerase	PGI	5.3.1.9	Brewer 1970
Phosphoglucomutase	PGM	2.7.5.1	Brewer 1970
Superoxide dismutase	SOD	1.15.1.1	

[1] Yeh, F. C., and D. M. O'Malley. 1980. Enzyme variation in natural populations of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) from British Columbia. I. Genetic variation patterns in coastal populations. Silvae Genetica (In press).

t seemed reasonable to assume, therefore, that the same enes were being expressed in different species.

Two measures of isozyme variation were evaluated. The umber of alleles per locus (A), was a count of the different llele phenotypes; heterozygosity per locus (H), was omputed from allele frequencies. The H values, derived rom Hardy-Weinberg expectations, were computed by ubtracting the sum of the squared allele frequencies for ach locus from 1.00. This measure was chosen instead of e direct count of heterozygotes because it is the value ost widely reported in the literature. Admittedly, it is a rst approximation that is accurate only when the trees ithin a species are randomly interbreeding, and when eographic differentiation within a species is lacking. lthough supporting data will not be provided here, the bserved proportions of heterozygotes per gene per species losely approximated the computed values.

The estimates of isozyme variation for the six species udied resulted in few general statements regarding riability (*table 3*). The values represented contrasts; for ample, the number of alleles per locus (A) for ACPH-2 ere low (2 or 3) in knobcone pine, sugar pine, and ouglas-fir, intermediate (5) in lodgepole and Jeffrey nes, and high (8) in loblolly pine. Heterozygosity (H) of CPH-2 was low for knobcone pine and sugar pine, 0.06 d 0.02, but high for Douglas-fir (0.49). ADH-2 had lues of A ranging from 2 to 6 with H values from 0.02 to 68. A and H are sometimes widely divergent: Jeffrey pine d 3 alleles for ADH-2 and an H value of 0.60; the perior trees in the loblolly sample had 5 alleles and a low estimate (0.06). GDH was homozygous in knobcone, ffrey, and sugar pines, but was highly variable within dgepole and loblolly pines. GOT-1 was nearly mozygous in Douglas-fir but variable in the five pine ecies. Characteristically, EST-1 had numerous alleles per us and high values for H, and LAP-1 and LAP-2 were riable in all six species.

Values for A and H averaged for all loci show differences r the six species in the study. In general, the A and H lues have similar trends. The average number of alleles r locus grouped into three general classes, with values ar 2, 3, and 4 (*table 3*). Knobcone pine had the lowest lue for A with an average of 2. Lodgepole, Jeffrey, and gar pines had values approaching 3 alleles; loblolly pine d Douglas-fir had high average values approaching 4 eles per locus. Average heterozygosity values ranged m a low of 0.13 for knobcone pine to a high of 0.36 for natural stand of loblolly pine; Jeffrey and sugar pines proached intermediate values; and, loblolly pine and uglas-fir averaged high H values.

I believe the two values for loblolly pine may be similar. ghtly different H values for these resulted from inclusion the additional loci in the superior tree sample. The litional loci did not modify the A mean values, but ally one allele was in high frequency. The result was the lition of several loci with low values for H. The data m the two sources of loblolly pine should not be used to ue that a higher average heterozygosity exists in natural stands than in a broad geographic sample of superior trees. When comparisons were restricted to the nine loci analyzed within both the natural stand and the select trees, the superior trees averaged more alleles per locus than the natural stand (4.78 compared with 3.89) and H values were similar for both samples.

Estimates of A and H for numerous species were compared by Brown and Moran (1981) and Hamrick and others (1981), but two points need mention. The lowest estimate of A and H for conifers has been found in red pine (Fowler and Morris 1977). In a sample of nine isozyme loci, no variation could be attributed to allelic differences; therefore, the estimates of genetic variation are A = 1.00 and H = 0.00. This finding is remarkable when compared with other conifers. It is, however, consistent with findings that red pine is highly self-fertile, has low variability in growth traits, and does not exchange genes with any other species. Some researchers would argue that significant genetic variance in phenotypic traits has yet to be demonstrated in red pine.

The estimates of nearly four alleles per locus and heterozygosities near one-third for loblolly pine and Douglas-fir are among the highest values obtained for any species of higher organism thus far reported (Hamrick and others 1981). As data become available for other conifers, a continuum of values for genetic variation in isozymes is expected. The six species reported here probably will rank from below average to among most variable.

LINKAGE

Isozyme analyses of female gametophytes tested deviations from independent assortment between gene loci. Data on genetic linkage were obtained on the five pines, but not on Douglas-fir. Highly heterozygous trees, identified in the species surveys for allele frequencies, were efficient items for estimating linkages. The number of pair-wise gene combinations increased exponentially with increasing numbers of heterozygous loci.

Pair-wise linkage of loci was established when the sum of the recombinant classes had depressed frequencies and the parental classes had inflated frequencies in comparison with random expectations. Species recombination values were computed from pooled single-tree estimates and all recombination values were adjusted to provide estimates of map distances in centiMorgans (cM) (Kasambi 1944). Complete data on sample size and segregation ratios will be published elsewhere; however, each distance was estimated with seed from a minimum of two different trees within each species. The minimum number of gametophytes used to estimate distances was 144 and the maximum exceeded 1000. Gene order was established by comparing distances in multiple heterozygotes. Because data were limited by the availability of appropriate multiple heterozygotes, not all gene combinations could be examined in each species.

Linked genes were distributed among several linkage blocks in the five pine species. Linkage maps were

Table 3–*Number of alleles per locus (A) and heterozygosity per locus (H) for five pine species and Douglas-fir*

Locus	Knobcone pine		Lodgepole pine		Loblolly pine (natural stand)		Loblolly pine (superior trees)		Jeffrey pine		Sugar pine		Douglas-fir	
	A	H	A	H	A	H	A	H	A	H	A	H	A	H
ACPH 1	2	0.06	2	0.04			4	0.33	4	0.27				
ACPH 2	2	0.06	5	0.41	7	0.32	8	0.20	5	0.40	2	0.02	3	0.49
ACPH 3			1	0.00										
ACPH 4	2	0.06	2	0.04			2	0.46						
ACO			2	0.21					3	0.40				
ADH 2	3	0.45	5	0.53	2	0.02	5	0.06	3	0.60	6	0.68		
ALD 1			2	0.04					2	0.33				
ALD 2			2	0.04					1	0.00				
CAT 1			2	0.04					3	0.35				
DIA 1			3	0.08					5	0.55				
DIA 2			3	0.08					2	0.25				
DIA 3									2	0.01				
DIA 4			3	0.26					2	0.32				
EST 1	6	0.46	7	0.52	6	0.72	9	0.51	6	0.63	3	0.34	8	0.69
EST 2			3	0.65					6	0.61				
EST 4			3	0.37	4	0.47	4	0.53	3	0.25				
FLEST			2	0.08					3	0.43				
GDH	1	0.00	3	0.30			3	0.37	1	0.00	1	0.00		
GOT 1	2	0.23	4	0.32	3	0.37	3	0.41	4	0.41	4	0.37	2	0.01
GOT 2	2	0.04			3	0.54			3	0.08	2	0.04	4	0.21
GOT 3	2	0.02	2	0.02	2	0.33	3	0.27	2	0.13	5	0.30	3	0.16
G6PD 1	2	0.04	2	0.08			3	0.22	3	0.16	3	0.08	4	0.54
G6DP 2	1	0.00	2	0.08			3	0.29	2	0.64	2	0.02	2	0.40
IDH	2	0.06	2	0.02			2	0.04	2	0.01	1	0.00	5	0.39
MDH 1	1	0.00	2	0.08			4	0.10	2	0.01	2	0.48	4	0.05
MDH 3	2	0.08	5	0.76			4	0.52	3	0.24	2	0.45	2	0.32
MDH 4	1	0.00	3	0.18			3	0.04	2	0.51	6	0.70	5	0.44
LAP 1	3	0.46	4	0.32	4	0.24	4	0.24	6	0.55	3	0.20	8	0.72
LAP 2	2	0.20	5	0.20	4	0.51	4	0.52	4	0.12	6	0.68	4	0.18
ALAP 1			2	0.25			3	0.08	3	0.31				
ALAP 2			2	0.10			3	0.13	4	0.32				
PEP 1			1	0.00					1	0.00				
PEP 2									1	0.00				
PER 1			2	0.21			4	0.51	3	0.45				
PER 2			7	0.65			7	0.40	5	0.64				
6PGD 1	2	0.43	2	0.04			8	0.65	3	0.28	2	0.48	3	0.14
6PGD 2	2	0.02	2	0.08			2	0.08	3	0.07			3	0.44
PGI 1			2	0.04					2	0.01				
PGI 2			2	0.04					3	0.24				
PGM	2	0.08	1	0.00	3	0.10	3	0.10	2	0.20	2	0.38	3	0.31
SOD 1	1	0.00	1	0.00			1	0.00	2	0.03	1	0.00	4	0.14
SOD 2	1	0.00	2	0.04					1	0.00	1	0.00		
SOD 3									1	0.00				
SOD 4									2	0.03				
SOD 5									3	0.39				
TOTAL	22		39		10		25		43		19		17	
A														
Mean	2.00		2.74		3.80		3.96		2.86		2.84		3.94	
S.E.	±0.22		±0.23		±0.49		±0.39		±0.21		±0.39		±0.42	
H														
Mean	0.125		0.185		0.362		0.282		0.261		0.275		0.331	
S.E.	±0.035		±0.032		±0.063		±0.038		±0.032		±0.057		±0.049	

[1] Construction of the table implies that a particular gene is common to all six species. No importance should be attached to the blanks within the table; species with the greater numbers of loci reflect laboratory advances over earlier analyses.

constructed with a common base using cM distances and linkage groups were indicated by capital letters (*fig. 1*).

A high proportion of the genes sampled were linked. Some were closely associated, others were separated by distances that required large sample sizes for detection.

The presence and arrangement of particular genes within chromosome segments for different species were not random; linkage blocks had common relationships for all species. Segment A, for example, was the longest linkage group found. For lodgepole, loblolly, and Jeffrey pines, the number of genes in linkage block A was large; for example, 12 for lodgepole pine. And the gene order within the block was almost identical for all five species. Three closely associated genes, GOT-1, PER-2, and PGI-2 anchored the left-hand portion of the segment, ADH-2 was 30 to 35 map units to the right, and EST-4 and G6PD-2 were to the right of ADH-2. Because LAP-2 was a substantial distance from ADH-2, the estimates were subject to large sampling errors. Nevertheless, ADH-2 and LAP-2 linkage estimates were statistically significant and map distances ranged from 25.4 in Jeffrey pine to 45.4 in sugar pine. In most species GOT-2 was difficult to resolve but some families provided estimates that located it to the right of LAP-2. Weak evidence suggests that linkage group A was linked with group B. If so, this means that a larger proportion of the genes in the total sample of loci were on a single chromosome. The evidence for linkage between blocks A and B needs further analysis; it is premature to consider them linked at this time.

Linkage group B was characterized by a block of three genes: EST-1, ALAP-1, and ACPH-2. They were found in the same order in lodgepole, loblolly, and Jeffrey pines with ALAP-1 in the center.

Linkage block C represented a long segment including FLEST and LAP-1. The main features of the D linkage block, investigated in lodgepole, loblolly, and Jeffrey pines, was a close linkage between IDH and GDH, with G6PD-1 located about 20 map units from IDH and GDH. In loblolly pine, GOT-3 was linked with ALD-1 with no recombination, and both genes were linked to ACPH-3 (linkage block E). One final linkage, block F, was observed between MDH-2 and TO-5 in families of Jeffrey pine.

Two reports of linkage groups in pines compare favorably with these findings. Rudin and Ekberg (1978) report a linkage block in Scots pine (*P. sylvestris* L.) consisting of GOT-1, ADH-1 and 2, LAP-2, and GOT-2 (*fig. 2*). Map distances in Scots pine are comparable to those reported for the species in this paper, and the arrangement is identical. Similar linkage in Scots pine is important because it samples the subsection *Sylvestres* which includes most pines of the Eastern Hemisphere. Guries and others (1978) found recombination frequencies of 0.03 and 0.04 between GOT-1 and PGI-2 (their GPI-2) for two trees of pitch pine (*P. rigida* Mill.) and these genes are tightly linked in lodgepole, loblolly, and Jeffrey pines.

Isozyme phenotypes led me to assume that many genes were common to different species and the linkage data supports this assumption. Genes, with common pheno-

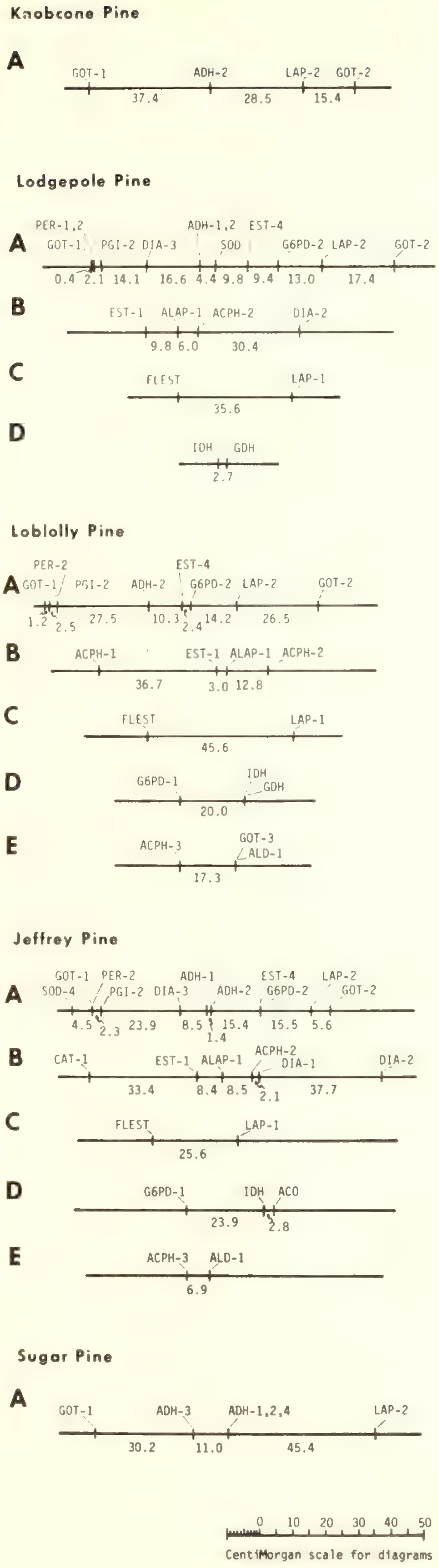

Figure 1—Linked genes detected in five species of pine with map distances in centiMorgan units.

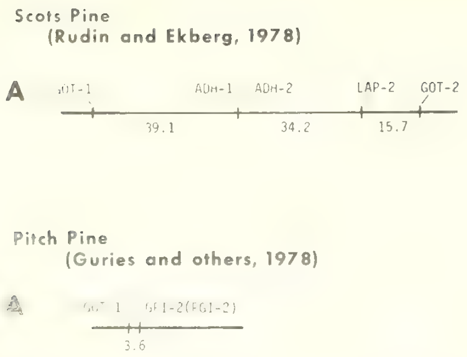

Figure 2—Linkage in two pine species, previously reported, compare well with the findings of this study.

types, map in the same order and with about the same distances in the different species.

Gene arrangement is highly conservative in the pines studied. These data indicate that evolution within the genus has not required large structural rearrangements within or between the gene blocks thus far examined. The linkage results invite comparison with other work on the arrangement of the genetic material in conifers. Specifically, the cytological studies of Sax (1960) and Saylor (1972) on pine chromosomes indicate that the karyotypes of conifers are uniform and almost indistinguishable. Major structural differentiation in the form of inversions and translocations is lacking, according to evidence from interspecific hybrids.

The interpretation of isozyme studies substantiate the conclusions of cytologists. Heterozygous inversions would suppress recombination, and inversion homozygotes would produce recombinants. If the trees differed for inversions, then linkage estimates could be expected to show wide divergence from tree to tree. Although more data are desirable, variances in linkage estimates from different trees in this study were within limits of random error and did not suggest the presence of inversion polymorphisms.

Saylor and Smith (1966) found no evidence of heterozygous translocations and the isozyme data support this observation. Translocations would disturb linkage relationships but linkage block A thus far demonstrates a consistent relationship between major genes in the block, not only within but also between the pine species thus far studied.

Data showed that about one-fourth to one-third of the sampled loci were associated with one linkage block; pines have 12 chromosomes, all but one or two with median centromeres (Saylor 1972). Twelve or 24 linkage groups might be expected, because whether considering the number of chromosomes or the number of chromosome arms, a random distribution throughout the chromosome complement of the 10 to 43 genes analyzed would lead one to expect a moderate number of linkages with low numbers of genes per linkage block. The likelihood of various numbers of genes being linked by chance on pine chromosomes, or on arms of chromosomes, can be approximated by the binomial distribution function. Linkage analyses evaluated about 35 genes and the expected distributions were computed on this basis (*fig. 3*). For 12 chromosomes, about 5 percent would not receive a gene, 15 percent would get one, 23 percent would have 2, and so on. This study indicated that as many as 12 genes were linked in the A block. The probability of a linkage block this large or larger on a chromosome is 1.5 X 10^{-5}. When chromosome arms are considered, the proportions of blocks with numerous genes are reduced. The probability of a linkage block with 10 or more genes on a chromosome arm is 1.0 X 10^{-7}

If we are to maintain that the large number of genes in the A linkage block results from some causal association of loci, the obvious observation is that the genes are all active during a specific developmental stage, namely, the growth of the developing embryo. The function of ADH, which is in the center of this segment, is the conversion of the end products of anaerobic respiration. Esterases are involved in the metabolism of fats and peroxidases are known to serve as IAA oxidases. These functions would implicate them in processes of embryo growth.

Close linkages suggest the possibility that selection operates upon specific allelic combinations. Fitness values for tightly linked loci depend on the multilocus combination of alleles rather than the fitness of individual loci (Lewontin 1974). Although pine species vary in the number of alleles per locus for the three tightly linked loci on the A block, GOT-1, PER-2, and PGI-2, three alleles per locus would produce 27 gametic classes and a total of 378 zygotic classes. The problem of estimating fitness values for such a complex system is overwhelming.

Lewontin (1974) cited Fisher's proposal that natural selection favors closer linkage of genes influencing the same polymorphism. Tight linkage could slow the process

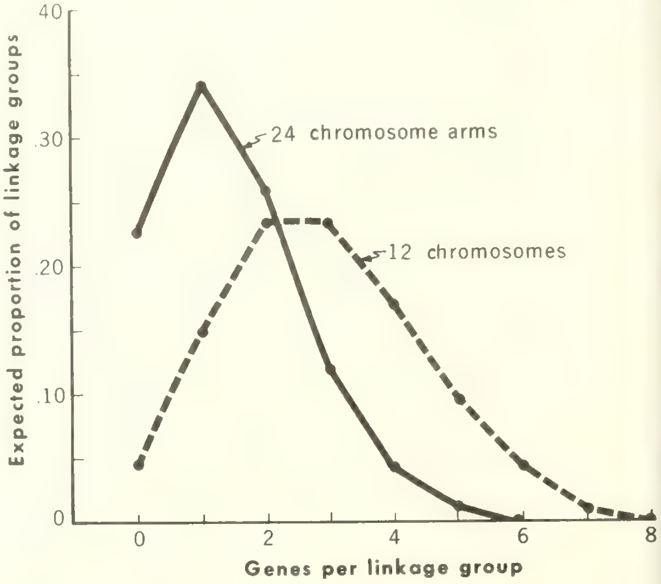

Figure 3—Expected proportion of linkage groups with different numbers of genes per group when 35 genes are randomly allotted to chromosomes and chromosome arms.

of allele fixation at a locus by operating upon complexes of oci and the effect could extend to include genes at greater map distances (Lewontin 1974). The analysis of pine loci points to a significantly large block of linked genes. One ould question if this linkage block represents genes that re related in function but sufficiently separated to ccommodate recombination.

Conifers stand, almost unchallenged, as higher organisms that readily yield information on isozyme linkage. Data in pines strongly suggest nonrandom association of umerous loci and provide new evidence on conifer volution. Allelic variation within these linkage blocks nay provide for precise genetic evaluation of species elationships. Linkages may also serve as the basis for napping and manipulating genetically controlled phenotypic traits. These possibilities bring closer the goal of elating genetic variation in enzymes to variation in henotypic responses; and conifers, once thought to be oor organisms for precise genetic analyses, offer dvantages over many, if not most, other higher rganisms.

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Analysis of Mating System Parameters and Population Structure in Douglas-fir Using Single-locus and Multilocus Methods[1]

D. V. Shaw[2] and R. W. Allard[3]

Abstract: Two methods of estimating the proportion of self-fertilization as opposed to outcrossing in plant populations are described. The first method makes use of marker loci one at a time; the second method makes use of multiple marker loci simultaneously. Comparisons of the estimates of proportions of selfing and outcrossing obtained using the two methods are shown to yield additional information about inbreeding and the genetic structure of populations. Single-locus estimates of the proportion of selfing in Douglas-fir were heterogeneous over marker loci and lower than estimates obtained with the multilocus estimator. Family structure and/or microhabitat selection were discussed as likely causes of the biased estimates of the proportion of selfing obtained from the single-locus estimation procedure.

An important goal of research in forest genetics is the development of methods that allow for the breeding of superior stock and also provide for the long-term maintenance of adequate germplasm resources. In realizing this dual goal, knowledge of the forces that are responsible for the distribution of genotypes in natural stands of forest trees, including mating system and gene flow, will be particularly useful. Several methods are available for the quantification of parameters which specify different aspects of mating systems, family structure, and gene flow. These methods have been used to estimate inbreeding coefficients (F) and the proportions of selfing (s) and outcrossing (t) (Sorensen 1973, Rudin 1977), as well as the effects of inbreeding depression on quantitative characters (Franklin 1970).

Electrophoretically detectable loci have been particularly useful in the study of mating systems and gene flow in plant populations (Brown and Allard 1970, Clegg and others 1978) for two main reasons. First, electrophoresis often provides an abundance of markers; second, enzyme loci are frequently codominant, allowing all genotypic classes to be identified directly and thus increasing the efficiency of the estimation procedures.

This paper presents estimates of the proportions of selfing and outcrossing in two stands of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) based on two different methods of estimation. We show that comparisons of the estimates from the two methods yield additional information about the mating system and about gene flow within and between stands of this species.

MATERIALS AND METHODS

The data we use to illustrate the estimation procedures are from a study of two stands of Douglas-fir. The two stands occupy ridge-top sites which are located about 40 kilometers east of Springfield, Oregon, and about 20 kilometers from each other. The two sites, Springfield 3 (S3) and Springfield 5 (S5), which are both at about 500-m elevation, are occupied by young stands of naturally regenerated trees. Trees on S3 are about 30 years of age and S5 contains trees of 40 to 45 years of age. The stands are composed almost entirely of Douglas-fir, with an occasional western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) interspersed. *Figure 1* gives the spatial distribution of the maternal trees sampled on the two sites. Sampling followed a modification of the Nelder Design (Nelder 1962).

Seeds were germinated and both diploid embryo tissue and haploid gametophytic tissue were analyzed by starch gel electrophoresis.[4] A minimum of 7 haploid-diploid pairs were anlayzed per maternal tree sampled. The following 11 loci were scored for each haploid-diploid pair (numbers in parentheses represent the number of alleles scored for each locus): Got-I (3), Got-III (3), G6pd (2), Gdh (2), To (2), Est (4), Lap-I (3), Lap-II (3), Pgi (3), Pgm-I (3), Pgm-II (3).

STATISTICAL TECHNIQUES

Single-locus Estimation

Fyfe and Bailey (1951) gave the theory of estimation of the proportion of selfing (s) and outcrossing ($t = 1 - s$) for the mixed mating model, using recessive markers. They used

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[1] Presented at the symposium on Isozymes of North American Forest Trees and Forest Insects, July 27, 1979, Berkeley, Calif.

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[3] Professor of Genetics and Agronomy, University of California, Davis, Calif.

[4] Starch gel electrophoretic techniques were developed by M. Thompson Conkle. (Personal commun. 1978.)

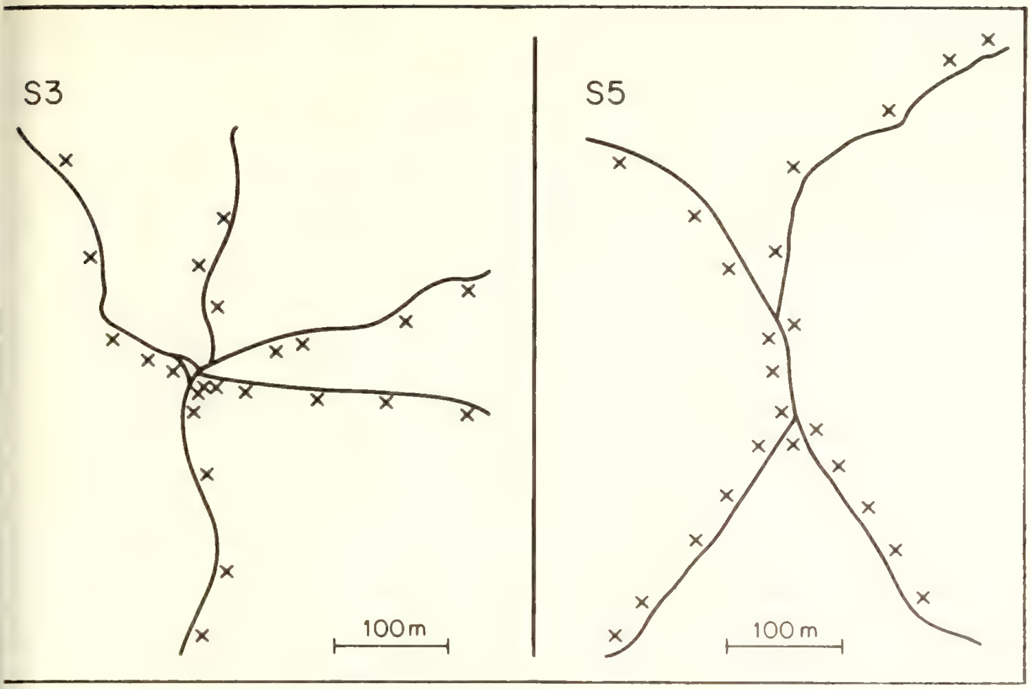

Figure 1—Spatial distribution of sample trees (*S3*) Springfield 3 site, (*S5*) Springfield 5 site.

he transformation f = (1-t)/(1+t), where f is the inbreeding oefficient, and formulated the joint maximum likelihood stimators and their variances for f and p (allelic frequenies). Brown and Allard (1970) and Clegg and others (1978) leveloped maximum likelihood methods for estimating utcrossing rates from the genotypic arrays of half-sib amilies in which the maternal parent is of unknown enotype. In these estimators the genotype of the maternal arent is inferred from the array of progeny produced by ach maternal individual. This inference is affected by the naternal genotype, by allelic frequencies in the pollen ool, and by the mating system parameters themselves. When data from gametophytes are also available, as in the resent case, the genotype of each maternal individual can e inferred from the gametic array of each maternal ndividual and an estimate of maternal genotypic frequenies can be obtained which is statistically independent of he other parameters. The estimator used in the present tudy was modified from that of Clegg and others (1978) to ake advantage of the information provided by the gameophytic analysis. Fyfe and Bailey (1951) pointed out that n important assumption of the mixed mating model is hat allelic frequencies are homogeneous in the pollen pool ver the entire area sampled. A variety of causes (for xample, family structure, microhabitat selection) can lead o heterogeneity of the pollen pool in natural stands and he resulting Wahlund effect leads to overestimation of the mount of selfing (Wahlund 1928). Consider the hypothetical sampling situation given by *figure 2.* Two contiguous tands, P_1 and P_2, are reproductively isolated from each ther but mating occurs at random within each stand. For diallelic locus the frequency of allele A_1 is 0.9 in P_1 and 0.1 n P_2. If an investigator were aware of the existence of the wo stands, and sampled the two areas separately, the single-locus estimator would yield correct estimates of the amount of selfing ($\hat{s} = 0$) and outcrossing ($\hat{t} = 1$). If, however, the investigator were unaware that there were two stands, and sampled as if there were only one stand, the estimate of s would be 0.89 and t would be 0.11. This example demonstrates the potential of pollen heterogeneity for introduction of bias into single-locus estimates, and it points out the need for careful sampling technique. Two important additional assumptions in the mixed mating model are: (a) that the probability of an outcross will not be affected by the maternal genotype and, (b) that selection does not intervene between mating and the determination of progeny genotype distributions. The fact that significant between-locus differences in s and t are often obtained from a single sample of progeny indicates that these assumptions, like the assumption of homogeneity of the pollen pool, are also often not valid.

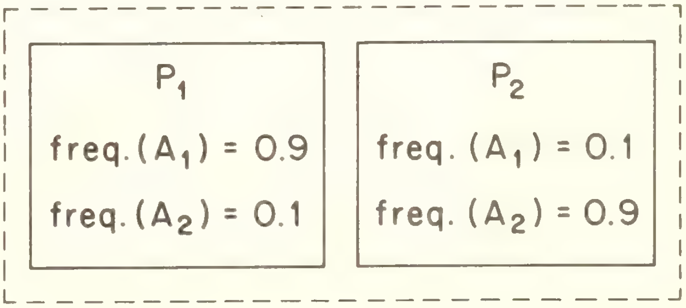

Figure 2—Hypothetical sampling situation showing actual stand boundaries (——) and sampling boundaries (– – –).

Multilocus Estimation

An alternate method for estimating proportions of outcrossing and selfing, which avoids many of the problems of single-locus estimation, has been developed.[5] The large number of marker loci provided by electrophoretic analysis makes application of this alternative method feasible in experimental situations. Briefly this method involves the identification of outcross progeny by the comparison of multilocus progeny genotypes with maternal genotypes and using the information gained from single-locus data for statistical compensation for outcrosses which are not identifiable. As more loci are considered the identification of true outcross progeny becomes nearly complete and estimates of s and t become increasingly dependent on observation and less dependent on statistical compensation. One advantage of this estimator is its insensitivity to failure of assumptions that can seriously affect single-locus estimation.

Another advantage is that comparisons of estimates derived from single-locus and multilocus techniques provide a means of separating the effects of selfing from other causes of nonrandom pollen dispersal, thus providing additional information concerning the breeding structure of populations.

RESULTS

Single-locus estimates of the proportions of outcrossing, t, for three loci in the Springfield 3 and Springfield 5 sites are presented in *table 1.* The estimates of t range of 0.66 to 0.97. This heterogeneity indicates that the estimates are affected by factors other than the mating system. Likelihood ratio tests indicate that 7 of the 9 single-locus estimates differ significantly from those expected under random mating (t = 1) and an eighth value approached significance (P = .06) (Rao 1973). Note also that the estimates obtained by combining the samples from the two sites are always lower than the mean of the two independent samples. This situation parallels the hypothetical case given in *figure 1* and demonstrates that bias is in fact introduced by combining heterogeneous samples.

Estimates of the proportion of outcrossing ($\hat{t}_m$) obtained using the multilocus estimator are given below.

Stand:	$\hat{t}_m$ (S.E.)
Springfield 3	0.91 (0.03)
Springfield 5	.93 (.02)
Combined	.93 (.02)

These estimates are based on 11 loci. The estimates do not differ significantly between the two sites and they are not affected by the combination of the samples from the two sites. These estimates probably reflect the actual proportions of self and outcross progeny which germinated and survived to the time of electrophoretic assay.

Table 1—*Single-locus estimates of outcrossing rates, $\hat{t}$ for two stands of Douglas-fir near Springfield, Oregon. Standard errors are in parentheses*

Stand	Locus		
	PGM	LAP	EST
Springfield 3	0.91* (.05)	0.90† (.05)	0.83**(.05)
Springfield 5	.93* (.05)	.98 (.05)	.66**(.06)
Combined	.91**(.02)	.79**(.03)	.71**(.03)

†, *, **The likelihood ratio test H_0: $\hat{t}=1$, is significant at probability levels, 0.06, 0.05 and 0.01, respectively.

Comparisons of single-locus and multilocus estimates of t are presented in *table 2.* Likelihood ratio tests were performed against the null hypothesis; H_0: $\hat{t} = \hat{t}_m$ (Rao 1973). The three loci each demonstrate a unique situation and they will be discussed separately.

1) Pgm-1: None of the three single-locus estimates of outcrossing based on this locus deviated significantly from $\hat{t}_m$ Combining the samples, therefore, did not generate any additional heterogeneity above and beyond the departure from randomness generated by the approximately 9 percent of selfing which occurred in both stands.

2) Lap-1: The single-locus estimate based on the combined samples differed significantly from $\hat{t}_m$. Thus the combining of data for the two stands introduced significant bias for this locus, indicating that allelic frequencies were not the same in the pollen pools of the two stands.

3) Est: All estimates based on this locus differed significantly from $\hat{t}_m$. This indicates that allelic frequencies in the pollen pool were not the same in the two stands and it indicates further that single-locus assumptions, probably including the assumption that the pollen pool is homogeneous within stands, do not hold.

DISCUSSION

A general expectation is that the pollen which falls on a given maternal tree is more likely to come from near neighbors than from distant trees. Also, the genotypes of neighboring trees may be more similar than those of

Table 2—*Comparison of multilocus with single-locus estimates of outcrossing rates for two stands of Douglas-fir near Springfield, Oregon*

Stand	$\hat{t}_m$	$\hat{t}$		
		PGM	LAP	EST
Springfield 3	0.91	0.93	0.90	0.83*
Springfield 5	.93	.93	.97	.69*
Combined	.93	.91	.79*	.71*

*Significant differences between $\hat{t}_m$ and $\hat{t}$ by likelihood ratio tests, at the .05 probability level.

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[5] Shaw, D.V., A.L. Kahler, and R.W. Allard. A multilocus method for estimating mating system parameters in plant populations. (Manuscript in preparation.)

andom trees in the population due to family structure or nicrohabitat selection. If such nonrandom distribution of ollen occurs over maternal trees, resulting estimates of elfing, s, made using the mixed mating model,will be larger han the true amount of selfing occurring in the populaion. In this study we compared estimates of selfing and utcrossing made with single-locus techniques, which are ffected by heterogeneity of pollen allelic frequencies, with nultilocus estimates made using a multilocus technique vhich is insensitive to such heterogeneity. With one locus Pgm-I) we observed no differences in single- and nultilocus estimates of selfing. However, with a second ocus (Lap-I) the results indicated heterogeneity of pollen ene frequencies between distant sites. With a third locus Est) heterogeneity was indicated both between distant ites and within small areas. Comparisons of single-locus stimates with multilocus estimates indicated within-stand eterogeneity of pollen gene frequency for one locus (and hus nonrandom pollen dispersal), whereas this effect was ot detected at other loci. Because different loci can give lifferent results, it is desirable to include several loci in tudies of mating systems.

Microhabitat selection, which causes individuals of imilar genotype to be clustered nonrandomly within opulations, is one possible cause of the heterogeneity bserved in Douglas-fir. Another possible cause is the endency of seeds to fall to the ground and grow near their naternal parent. The result of this restricted seed dispersal s that relatives, whose genotypes are more similar than hose of random members of the populations, become oncentrated in family clusters. Such nonrandom distribuion of genotypes might lead to heterogeneity of the pollen ool. It can also lead to inbreeding: near neighbors are nore likely to be relatives and they are also more likely to nate than are random members of the population.

The demonstration that nearly 10 percent of assayable mbryos in Douglas-fir resulted from self-fertilization, and the indications that additional types of assortative matings may also occur, provide evidence that substantial inbreeding occurs in this species. Douglas-fir, however, shows moderate to severe inbreeding depression which raises the question of the equilibrium level of inbreeding that develops in response to the effects of these opposing forces. *Table 3,* which gives Est genotypic frequencies of adult maternal individuals and also genotypic frequencies of the progeny of these same individuals, provides information on this point. In the progeny generation homozygotes are in excess and heterozygotes are in deficiency. This is expected when mating is known to be assortative and when seedlings are assayed at a sufficiently early stage such that little selection is likely to have occurred between mating and time of assay. However, genotypic frequencies in the adult parents give a good fit to expectations based on the trinomial square rule. This pattern was repeated for the Lap-I and Pgm-I loci, using combined samples from the two stands (combined samples were used to obtain adequate sample sizes). Thus, even though significant inbreeding occurs in Douglas-fir, leading to excesses of homozygotes over expectations based on the assumption of random mating, it appears that selection removes the excess of inbred individuals. The adult populations fit Hardy-Weinberg expectations but only because the effects of nonrandom mating and selection balance and cancel each other.

Table 3–*Test for goodness of fit for Esterase genotypes to expectations assuming random mating for the parents and the progeny of the combined Springfield samples*

Class	Genotype					
	11	22	33	12	13	23
Progeny						
Observed	45	150	68	104	50	90
Expected	29.2	121.7	37.0	117.2	65.7	134
Chi-square$_{(3)}$	= 61.24***					
Parents						
Observed	1	14	3	9	8	14
Expected	1.76	13.2	4.1	9.6	5.8	14
Chi-square$_{(3)}$	= 1.88 n.s.					

***The chi-square goodness of fit test, with 3 degrees of freedom is significant at the .001 probability level; n.s. indicates nonsignificant deviation.

In this paper we have illustrated methods of studying the mating system and breeding structure of populations of forest trees. Analysis of preliminary data from an experiment with Douglas-fir indicates that significant numbers of self-fertilized embryos survive through embryonic stages in this species, and that other phenomena, such as family structure and habitat selection, may also contribute to nonrandomness in family arrays derived from open pollination.

Knowledge of the breeding structure in natural stands of forest trees may influence the interpretation of results from open-pollinated genetic tests, and may be useful in planning plus-tree selections and germplasm conservation programs. The methods described appear to provide information useful to the planning and development of tree breeding programs.

Acknowledgments

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Isozyme Studies of Forest Insect Populations[1]

Molly W. Stock[2]

Abstract: Data from isozyme analyses are being used to help answer many basic biological questions about forest insect pests and to provide information for a variety of other purposes as well. This paper summarizes the uses of isozymes in quality control of laboratory insect colonies, in studies of insecticide response, as markers of insect parasitoids, and in investigations of species relationships and population differentiation, including patterns of dispersal.

Until recently, genetic studies in forest entomology were handicapped by two rather general assumptions (Wellington 1977). One was that individuals and populations within species are homogeneous units that will behave similarly when treated in a certain way or when subjected to certain environmental conditions. This is an extension of the "if you've seen one, you've seen them all" attitude mentioned earlier in this symposium. If, for example, a particular silvicultural treatment affected an insect population in a certain way in one area, it was often assumed that all other populations of that insect species would respond similarly. A second assumption that hindered initiation of applied biochemical genetics research is a corollary of the first. That is, numerical changes in insect populations (outbreaks, population crashes, and other events) could be explained adequately by understanding external factors affecting the populations.

The life system concept of Clark and others (1967) exemplifies a more realistic approach. According to this scheme, an organism's phenotype and, ultimately, its success in terms of population numbers and persistence, results from the interaction of the genetic makeup of its component individuals with the effective environment.

Since 1974, the importance of intrinsic genetic variation in insect population dynamics has been taken into account in the development of research programs aimed at managing forest insect pests. Data from isozyme analyses are being used to answer basic biological questions and are contributing greatly to our understanding of insects that attack forest trees.

To illustrate the range of isozyme uses in forest entomology, I will summarize some of these research areas.

QUALITY CONTROL OF LABORATORY INSECT COLONIES

Many of the problems associated with conserving genetic resources of forest trees are similar to those dealt with in establishing and maintaining laboratory colonies of insects.

Genetic variation is high in natural populations of insects. This variation is reduced when a limited sample from one area of an insect's range is taken to propagate a laboratory colony. If the number of individuals used to start the colony is small, genetic variation is further reduced in subsequent generations by inbreeding. Colony insects become closely adapted to the laboratory environment and, unless precautions are taken, they may lose the adaptive flexibility characteristic of the wild population. In addition, they may come to differ in important ways from the wild population, making information derived from then of limited value (Bush 1977). After many generations in the laboratory, for example, cultured Lepidoptera, such as budworms and tussock moths, often prefer artificial media to foliage, and groups that diapause (undergo a dormant phase) in the field may become nondiapausing in the laboratory. Although these qualities make the insects easier to rear, their responses in experiments may vary from those of their wild counterparts.

Because responses of colony insects under controlled conditions in the laboratory are often used to estimate behavior of natural populations, it is essential that the degree of overall similarity between the laboratory colony and that of the wild population be known. It is also essential that the colony be monitored over time to detect any further divergence in genetic diversity from wild populations. Quality control—precise, detailed information on differences between laboratory colonies and wild populations, obtained using isozyme analyses—promises to be an integral part of the maintenance of laboratory insect colonies in the future.

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GENETICS OF INSECTICIDE RESPONSE

Because they provide a means of identifying insecticide-resistant genotypes, isozyme analyses have been of great value in relating the presence or absence of specific enzymes to insecticide response. Several studies have shown that changes in esterase sensitivity to inhibition by organophosphorus and carbamate insecticides can confer high levels of resistance (Plapp 1976, Georghiou and Pasteur 1978). Marked differences may occur between esterase zymograms of susceptible and resistant insect groups. For example, the organophosphorus insecticide, dimethoate, acted as a selective agent on esterases of the olive fruit fly; insects that were heterozygous at one of two polymorphic esterase-producing gene loci had a better chance of surviving (Tsakas and Krimbas 1970). Pasteur and Sinegre (1975) found a high correlation between certain gene frequencies at an esterase locus in a mosquito and sensitivity to the toxicant, Dursban.

Among forest insects, inter- and intra-specific differences in response to chemical control agents have been observed repeatedly in the field and, more recently, have been demonstrated in controlled laboratory tests. Robertson and others (1978a) compared the response of six budworm species to selected insecticides and found no single species consistently most or least susceptible to these chemicals. It has been common practice, however, when an insecticide has not been tested on a particular species, to predict its response from results of tests on closely related species. Differential response to insecticides has also been shown in laboratory tests on Douglas-fir tussock moth populations (Robertson and others 1978b).

Effective integrated control of forest pests requires that variations within and between species in insecticide response be more fully assessed and considered. Toward this end, isozyme analyses are now being used on these insects. For example, recent work has shown a relationship between gene frequencies at an esterase locus and insecticide resistance in the tussock moth (Stock and Robertson 1979).

Although, like other areas of isozyme application, this work is in its early phases, we may look ahead to a time when levels of insecticide tolerance can be estimated by simple electrophoretic analyses. From a practical standpoint, adoption of routine genetic assays as part of insect population surveys before implementation of control operations could provide estimates of population response to various insecticides. Ultimately, such information could help in the decisionmaking processes involved in integrated pest management.

MARKERS OF INSECT PARASITOIDS

Parasitoids—parasites that kill the host—are important in natural control of pest insect populations. Techniques to rapidly and accurately assess levels of parasitism are essential in the development of integrated control programs. Parasitism levels are presently assessed through host dissection, which is tedious and often inaccurate, or rearing hosts until parasitoids emerge, a procedure that delays estimates of percent parasitism and requires laboratory space, time, and personnel during the field season. Electrophoresis is emerging as a promising practical alternative to these methods. Because host insects and their parasitoids belong to different taxonomic groups, some isozymes are characteristic enough to be readily associated with one or the other species. On this basis, the presence and identification of parasitoids can be determined (May and others 1977a, Wool and others 1978).

SPECIES RELATIONSHIPS

The value of isozyme data in elucidating systematic relationships is well known (Avise 1974, Ayala 1975). On the basis of electrophoretic differences, for example May and others (1977b) separated the human biting blackfly in Maine from several isomorphic species that do not feed upon humans.

Isozyme information is helping us unravel some taxonomic problems with forest insects, such as the spruce budworm, a species complex described by Freeman in 1967. Most of these recent budworm divisions are based upon traditional morphological comparisons. The large amount of variation present among populations, however, has resulted in considerable uncertainty as to the species status and degree of isolation of many of these groups. In all species, both polymorphic and continuously variable characteristics appear in size and color of larvae, pupae and adults (including wing markings), host plant preferences, cold hardiness, diapause characteristics, and seasonal timing of developmental stages. In addition, varying degrees of reproductive isolation between sympatric species and between allopatric populations within some species occur. To clarify relationships in this group, an integrated approach incorporating pheromone analyses, isozyme analyses, and traditional morphological studies is being used. The electrophoretic method is thus providing a valuable addition to classical approaches to taxonomic studies of forest insect pests.

POPULATION DIFFERENTIATION

Effective control strategies for forest insects are based on a thorough understanding of the population dynamics of each pest. As we learn more about how insect populations are adapted to specific regional host types, we come closer to a management scheme that minimizes disruption of the ecological system of which the pest insect is part. Toward this end, isozyme studies are proving of considerable value. We have begun to answer questions about population differentiation of pest insects as it relates to adaptation to sympatric host plant varieties or species (Bush 1975). The mountain pine beetle, for example, attacks a diversity of coniferous forest trees over its range, with host species preference varying from place to place. In a mixed stand, the beetles may attack lodgepole pine and apparently ignore other tree species. In a nearby stand, another tree species might be attacked while lodgepole pine goes relatively uninfested. These and other differences revealed in the field and laboratory experiments suggest that stratification of sympatric mountain pine beetle populations may be occuring in many areas. Preliminary work in our laboratory suggests that beetles attacking white pine and lodgepole pine in northern Idaho have different characteristic acid phosphatase frequencies. Similar types of differentiation have been observed in mountain pine beetle populations in Colorado.[3]

Larger differences have been noted between insects in different host tree types when geographic barriers restrict gene flow between them. For example, considerable genetic divergence has occurred between Douglas-fir beetles in Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) in coastal Oregon and Douglas-fir var. *glauca* [Beissn.] Franco in northern Idaho (Stock and others 1979). This work supports evidence of behavioral and physiological differences between the two groups of beetles and underlines the necessity for using caution in extrapolating information obtained on one population to the other when control measures are being planned.

Regional population differentiation is also being examined in the southern pine bettle (Namkoong and others 1979), the forest tent caterpillar,[4] the eastern spruce budworm, [5] and several other species of spruce budworm. In the western spruce budworm, we are applying isozyme studies toward clarification of patterns of gene flow among Pacific Northwest populations. It has not been clear, for example whether new budworm outbreaks originate by dispersal from older outbreaks or whether they derive from ow-density populations already present in an area. To help answer this question, we have examined genetic characteristics of 20 outbreak populations of western spruce budworm in Idaho and Montana (Willhite 1979). In this work, one technique that has proven useful is the study of shared rare alleles among the populations (Pashley and Bush 1979). It appears that in some areas of Montana, dispersal plays a more important role in the spread of budworm outbreaks than was previously believed. We have also been able to delineate major patterns of gene flow over the area to help aid prediction of future trends in the spread of budworm outbreaks.

In summary, the union of electrophoretic methodology with applied research in forest entomology is certainly a promising one and we welcome opportunities, such as we have had here today, to exchange ideas and work toward development of productive integrated research programs in forestry.

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Associations Between Heterozygosity and Growth Rate Variables In Three Western Forest Trees[1]

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Abstract: For each of three species, quaking aspen, ponderosa pine, and lodgepole pine, we determined the relationships between a ranking of heterozygosity of individuals and measures of growth rate. Genetic variation was assayed by starch gel electrophoresis of enzymes. Growth rates were characterized by the mean, standard deviation, logarithm of the variance, and coefficient of variation of annual ring widths measured from cores. In aspen, heterozygosity was associated with high mean growth rate, but in ponderosa and lodgepole pines heterozygosity was not associated with mean growth rate. High levels of heterozygosity were associated with high growth variability in aspen and ponderosa pine, and with low growth variability in lodgepole pine.

Several frequently observed phenomena suggest strong genetic influence on growth characteristics of forest trees. When trees from different origins are grown in common gardens they show marked differences in growth traits (Squillace and Silen 1962, Weidman 1939). These interpopulation differences are thought to be primarily the result of natural selection forming adaptations to local environmental conditions. Differences in growth characteristics are seen also between trees within a single population. Genetic differences within a population arise from segregation and a variety of mating types; some individuals are produced by selfing, some by outcrossing between related individuals, and some by outcrossing between unrelated individuals. These matings produce progeny with relatively low, intermediate, or high levels of heterozygosity, respectively. One generation of selfing, for example, reduces heterozygosity by one-half relative to outcrossing. In selfed progeny, an increase in homozygosity of deleterious recessive alleles may result in a lack of vigor (Fowler 1965, Sorensen and Miles 1974). In outbred progeny, however, increased vigor may result from heterosis because of a summation of heterozygote superiority over many loci. Heterosis for growth and viability is commonly observed in crosses between strains of domesticated plants and animals.

This paper considers the relationships between heterozygosity and growth rate variables within populations of three forest tree species. In this study, we used starch gel electrophoresis to determine heterozygosity of several protein genotypes and estimated mean growth rate from measurements of annual radial growth rings taken from increment cores.

THEORETICAL BACKGROUND

Considerable theoretical and empirical evidence suggest that heterozygosity is associated with fitness and morphological variation.

Heterozygosity Associated With Fitness

Heterosis with respect to growth or viability has been reported extensively in crosses between strains or stocks of domesticated plants and animals (Lerner 1954). Offspring from these crosses have levels of heterozygosity higher than those maintained in either parental stock. Experiments have been designed to detect heterosis in individuals that differ in either heterozygosity of a single pair of chromosomes or a few allozyme loci. For example, chromosomes may be made heterozygous or homozygous in several species of *Drosophila*. When heterozygotes were compared to homozygotes, the homozygotes had fitnesses of only 10 to 20 percent that of the heterozygotes (Sved and Ayala 1970, Tracey and Ayala 1974). In three species of marine pelecypods—the blue mussel, *Mytilus edulis*, the ribbed mussel, *Modiolus demissus*, and the California mussel, *Mytilus californianus*—the proportion of heterozygotes at one or more loci increased with size (Koehn and others 1973, Koehn and others 1976, Tracey and others 1975). Size is highly correlated with age in these animals, so this relationship probably results from higher viability of heterozygotes. In individuals of the common killifish *Fundulus heteroclitus*, heterozygosity of twelve polymorphic loci was monitored for several years in two localities. Fish could be aged accurately by size, so the same cohort of fish was sampled in successive years. In both localities, level of heterozygosity increased with age, and the data were interpreted as evidence for higher viability in individuals with higher heterozygosity (Mitton and Koehn 1975). In the slender wild oat *Avena barbata*, viability differentials favoring heterozygotes were found at each of three esterase loci (Clegg and Allard 1973). In populations of Colias butterflies, *Colias philodice eriphyle* (Watt 1977) and the sagebrush lizard *Sceloporus graciosus* (Tinkle and Selander 1973), heterozygosity increased steadily throughout the life cycle.

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Heterozygosity confers advantages for other aspects of fitness. Growth rates recorded for the American oyster *Crassostrea virginica,* were higher for heterozygotes for several loci than for homozygotes (Singh and Zouros 1978). In the tiger salamander *Ambystoma tigrinum,* growth rates in the field and in the laboratory were associated with heterozygosity of a few allozyme loci. Higher growth rates in highly heterozygous individuals could be detected within the progeny of a single pair cross raised in the laboratory.[4] A study of the demography of the perennial composite *Liatris cylindracea* revealed that highly heterozygous individuals attained greater size and produced more seeds than highly homozygous individuals (Schaal and Levin 1976). Heterozygosity at a single, highly polymorphic locus in the dark-eyed junco, *Junco hyemalis,* was found to be related to both dominance rank and viability; heterozygotes generally enjoyed higher positions in the dominance order than homozygotes, and also survived stress tests better than homozygotes (Baker and Fox 1978).

The papers cited in this section represent careful studies that gave positive results. Equally careful and comprehensive studies have led some investigators to conclude that allozyme variation is essentially unrelated to either fertility or viability (Christiansen and others 1973, Mukai 1977, Yamazaki 1972).

Heterozygosity Associated With Morphological Variation

Associations between heterozygosity and morphological variation are interesting primarily because variation in morphology may be associated with variation in fitness. To date, the majority of studies of associations between heterozygosity and morphological variation have been conducted utilizing data from several or many populations. In studies comparing a series of island populations, for example, the proportion of polymorphic loci and the level of heterozygosity for a population have been related to the degree of morphological variation in those populations. In both the side-blotched lizard *Uta stansburiana* (Soulé and others 1973) and in macaques *Macaca* sp. (Morris and Kerr 1974), populations with more polymorphic loci and higher levels of heterozygosity showed higher levels or greater ranges of morphological variation. Soulé and others (1973) pointed out that these observations suggest allozyme variation is a reasonable indicator for genetic variation throughout the genome. The studies just cited agree in that populations with greater numbers of genotypes show greater morphological variation.

We are concerned here with heterozygosity, not as it affects variation between populations but, rather, within populations. Lerner (1954) presented a large body of evidence, primarily from domesticated animals and plants, to support his hypothesis that high levels of heterozygosity enhanced developmental homeostasis among individuals within populations. He proposed that highly heterozygous individuals have lower levels of phenotypic variation than do predominantly homozygous individuals. Lewontin (1956) stressed that homeostasis is most evident for traits directly involved in the determination of fitness. An extension of Lerner's hypothesis is that comparisons of individuals with different levels of heterozygosity, but sampled from the same randomly mating populations, have differences in the levels of developmental homeostasis. The effects of heterozygosity upon developmental homeostasis can be measured when only single chromosomes or a few allozyme loci are used to construct groups with low or high heterozygosity. When viability and fertility in *Drosophila* homozygous or heterozygous for specific chromosomes were compared, heterozygous individuals had lower variance in both traits (Dobzhansky and Wallace 1953). Similarly, when Robertson and Reeve (1952) compared *Drosophila* heterozygous or homozygous for specific chromosomes, they found that heterozygotes had lower variance in wing morphology. By using the level of bilateral asymmetry of side-blotched lizards to estimate their degree of developmental homeostasis, Soulé (1979) found that developmental homeostasis increased with heterozygosity as measured by allozyme loci. When populations were divided into homozygous and heterozygous classes on the basis of single allozyme markers, homozygous classes had higher phenotypic variation for both the common killifish *Fundulus heteroclitus* (Mitton 1978) and the monarch butterfly *Danaus plexippus* (Eanes 1978). These data support the extension of Lerner's hypothesis mentioned earlier: developmental homeostasis can vary with levels of heterozygosity within populations, and the effect of heterozygosity may be detected when only single chromosomes or a few allozymes are used to sort individuals into different levels of heterozygosity.

Relationships between heterozygosity and some aspects of fitness have been found primarily in studies of animals. Long-lived forest trees, however, are subjected to much temporal and spatial heterogeneity during their life cycle and recent reviews indicate that forest trees harbor more genetic variation than other groups of plants or animals (Hamrick 1979, Hamrick and others 1979, Hamrick and others 1981).

This paper discusses the results of recent investigations of forest trees to rank individual trees for levels of heterozygosity and to assess how these ranks relate to mean growth rate and variability of growth rate. Examples are taken from three species native to the Colorado Rocky Mountains: quaking aspen *Populus tremuloides* Michx., ponderosa pine *Pinus ponderosa,* Dougl. ex Laws., and odgepole pine *Pinus contorta* Dougl. ex Loud.

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[4] Pierce, B. A., and J. B. Mitton. *Growth and heterozygosity in the tiger salamander, Ambystoma tigrinum.* (Manuscript submitted for publication.)

MATERIALS AND METHODS

Mean growth rate and variability of growth rate were estimated from annual radial growth ring measurements obtained from one core extracted from each tree. A binocular stereoscope fitted with an ocular micrometer was used to measure ring widths. For each tree, three measures of variability in growth were calculated: the variance, the standard deviation, and the coefficient of variation.

Vegetative or gametophytic tissue was subjected to starch gel electrophoresis and heterozygosity scores were obtained directly from the banding patterns on gels. The number of loci heterozygous were summed to obtain an ndividual heterozygosity score for each clone or tree. If four loci were being scored for each individual, for example, the possible heterozygosity score ranged from 0 o 4.

The analytical techniques of multiple regression and analysis of covariance compared growth characteristics among individuals of different heterozygosity levels. These techniques offer the advantage of removing the confounding effects of independent variables that are strongly correlated.

Aspen

In the Western United States, aspen reproduces predominantly asexually by sending up ramets from lateral roots. The unit of study in this species is, therefore, the clone, and cores from the largest ramets within a proximity of about 10 m were used to estimate growth rate variables. Aspen is dioecious, and the sex of each clone was determined in the spring by examining catkins. Age, sex, elevation, and growth rate variables were recorded for each of 106 clones at elevations from 1700 to 3100 m west of Boulder, Colorado. In addition, genotypes at three loci—peroxidase, phosphohexose isomerase, and glutamate dehydrogenase—were obtained from leaf tissue for each clone (Mitton and Grant 1980).

Ponderosa Pine

Pollen tissue from 114 trees on a ridgetop and a south-facing slope at an elevation of 2590 meters near Glacier Lake was analyzed for four loci—peroxidase, aminopeptidase, phosphohexose isomerase, and phosphoglucomuase (Knowles 1978).

Lodgepole Pine

Needle tissue was sampled from 152 lodgepole pines at he University of Colorado's Mountain Research Station, Ward, Colorado, at an elevation of 2800 m. Needle tissue was prepared for electrophoresis (Mitton and others 1979) to obtain genotypes for four loci—peroxidase, fluorescent esterase, phosphohexose isomerase, and alcohol dehydrogenase.

Table 1–*Distributions of loci heterozygous per individual in quaking aspen, ponderosa pine, and lodgepole pine*

Sample	Sample size	Loci studied	Heterozygous loci 0	1	2	3	4
Quaking aspen	100	3	40	41	15	4	-[1]
Ponderosa pine	117	4	23	57	30	7	0
Lodgepole pine	152	4	32	69	42	9	0

[1] Dash indicates that this number of loci was not considered.

RESULTS

Results of starch gel electrophoresis were summarized for each population sample as a distribution of the number of loci that were heterozygous per individual (*table 1*).

Aspen

Correlations among variables complicated the search for an association between heterozygosity and growth rate. Growth rate varied with age, sex, and elevation, and distribution of the sexes was not random with respect to elevation. At low elevations, females outnumbered males slightly, and at high elevations, males outnumbered females by 2:1, or more. Growth rate of females was superior to that of males at all elevations, but female growth rate dropped more sharply with increasing elevation (Grant and Mitton 1979). Radial growth decreases regularly with increasing age of a stem (Fritts 1976). Data were analyzed by multiple regression, with mean growth rate of a clone as the dependent variable, and age of the oldest standing ramet, sex, elevation, and heterozygosity for each clone as independent variables (*table 2*). The multiple R indicated that the suite of independent variables accounts for about 28 percent ($p < 0.001$) of the variance in mean growth rate among the clones. As expected, growth rate decreased with age and elevation, but was not affected by sex in this analysis. With

Table 2–*Multiple regression analysis of standard deviation of annual ring width in quaking aspen*

	Coefficients	Probability
Multiple R	0.530	$P < 0.001$
Independent variables		
Age	–0.064	$P < 0.001$
Heterozygosity	.811	$P < 0.05$
Sex	.593	n.s.
Elevation	– .008	$P < 0.01$

the effects of other variables held constant, the relationship between heterozygosity and growth rate was significant. The range of heterozygosity in this sample was 0 to 3 and mean growth rate increased with the number of heterozygous loci ($p < 0.05$).

Within this sample of clones, mean growth rate and variance of growth rate were highly correlated ($r = 0.92$, $p < 0.001$). This suggests that the average growth rate and the variability of the growth rate over time are intimately associated in some way. A multiple regression performed with the same independent variables but with either variance or standard deviation of growth rate as dependent variables gave similar results; increases in the number of heterozygous loci were associated with increases in growth variability.

Ponderosa Pine

Ponderosa pine sampled near Glacier Lake were distributed over a ridgetop and a south-facing slope. Age structures, growth rates, and gene frequencies for some of the four loci differed between these geographically adjacent but ecologically distinguishable sites (Knowles 1978). Mean growth rate and age were negatively correlated ($r = -0.057$, $p < 0.001$). To eliminate the confounding effects of age, slope aspect, and mean growth, an analysis of covariance was employed. A growth rate variable was the dependent variable, a heterozygosity class was the independent variable, and age, slope aspect, and mean growth rate were covariates. The effect of heterozygosity on mean growth, therefore, could be tested with the effects of age and slope held constant; or, the effect of heterozygosity on variance of growth rate could be tested with the effects of age, slope, and mean growth rate held constant. For this analysis, heterozygosity scores were pooled to create two classes—those predominantly homozygous (0 to 1 loci heterozygous) and those predominantly heterozygous (2, 3, or 4 loci heterozygous).

An analysis of covariance, with mean growth rate as the dependent variable, revealed no differences between trees predominantly heterozygous and those predominantly homozygous (*table 3*). Analyses of covariance were also done with the standard deviation, the logarithm of the variance, and the coefficient of variation used to characterize growth variability (*table 4*). Results of these analyses were all consistent, and were either statistically significant or at the borderline of significance. Although mean growth rates did not differ between heterozygosity classes, variability of growth rates over time were different for heterozygotes and homozygotes. Growth of heterozygotes was more erratic from year to year than was growth of homozygotes.

Lodgepole Pine

A relationship between genotype and growth rate was tested in lodgepole pine. The pines sampled for this analysis were all from a single relatively homogeneous site. Within this sample of 152 trees, age and mean growth were positively correlated ($r = 0.19$, $p < 0.05$); although within any tree radial increments tended to decrease with age. To correct for the effect of age, analyses of covariance were done with mean growth rate or coefficient of variation as the dependent variable, heterozygosity class as the independent variable, and age as the covariate. The mode for the distribution of individual heterozygosity was at 1, and none of the trees in this sample were heterozygous for all four of the loci (*table 1*). Once again, heterozygosity scores were pooled to create two classes, predominantly homozygous (0 to 1 loci heterozygous) and predominantly heterozygous (2 or 3 loci heterozygous). In this analysis, the contribution of the covariate (age) was not significant, so that similar results could be obtained with a single classification analysis of variance, or with a t-test between means. Mean growth rates did not differ between heterozygosity classes but the classes differed in variability of growth rates. The distribution of coefficients of variation of growth rates (*fig. 1*) shows that, although there was considerable overlap in growth variability between heterozygosity classes, the predominantly heterozygous individuals had a mean of 70.3, in contrast to the predominantly homozygous individuals, which had a

Table 3—*Comparisons in ponderosa pine and lodgepole pine of mean growth increment between predominantly homozygous and predominantly heterozygous individuals*

Locality	Heterozygosity level	Trees	Unadjusted mean	Adjusted mean	F[1]	Probability
Glacier Lake (Ponderosa pine)	Low	78	14.55	15.21	0.15	P>0.50
	High	36	16.62	15.11		
Ward (Lodgepole pine)	Low	101	5.30		1.10	P>0.50
	High	51	5.58			

[1] F statistics for ponderosa pine analyses are from analyses of covariance, with age and slope as covariates. Adjusted values incorporate adjustments for covariates. F statistic for lodgepole pine is based on analysis of variance.

Table 4—*Comparisons at two localities in ponderosa pine of annual growth increment variabilities between trees of different heterozygosity labels*

Locality	Heterozygosity Level	Trees	Standard Dev.		Probability	Log of Variance		Probability	Coef. of Variation		Probability
			unadj.	adj.		unadj.	adj.		unadj.	adj.	
Glacier Lake	Low	78	9.36	9.68	<0.05	1.87	1.88	<0.05	59.33	58.45	$0.10 > p > 0.05$
Glacier Lake	High	36	11.18	11.07		1.01	1.01		63.35	65.26	

Note: Significance levels come from analyses of covariance. Age, slope, and mean growth rate are covariates for standard deviation and logarithm of the variance, and slope and age are covariates for the coefficient of variation. Each probability corresponds to the contrast immediately to its left in this table.

mean of 79.2 The differences between the means were statistically significant. Once again, level of heterozygosity was associated with growth variability, but the direction of the relationship found in lodgepole pine was opposite to those found in ponderosa pine and aspen; that is, in lodgepole pine, high heterozygosity was associated with low variability in growth rate.

DISCUSSION

The data presented here from quaking aspen, ponderosa pine, and lodgepole pine are consistent with data from previous studies in that they find a relationship between heterozygosity and some measure of growth rate. Although we do not find an association between mean growth rate and heterozygosity in either ponderosa pine or lodgepole pine, mean growth rate of highly heterozygous clones of aspen are higher than those of predominantly homozygous clones, just as the mean growth rates of highly heterozygous American oysters (Singh and Zouros 1978) and tiger salamanders[5] exceed those of more homozygous individuals. These observations may be considered extensions of Lerner's (1954) hypothesis to smaller and smaller portions of the genome. For example, Lerner established that high heterozygosity in the progeny of crosses between domesticated strains or stocks often bestows vigor in the progeny. The same phenomenon, on a much finer genetic scale, is apparent in our results; aspen clones that are heterozygous for a few loci have growth rates that exceed those of homozygotes. Also, variability in ring width in all species is related to level of heterozygosity, and in this respect, these results are similar to those of Mitton (1978), Eanes (1978) and Soulé (1979).

The results of tests for associations between heterozygosity level and growth variability are consistent in the three species studied in that associations were significant in each species. They are inconsistent, however, in their directions. Predominantly heterozygous individuals show higher growth variability in aspen (*table*

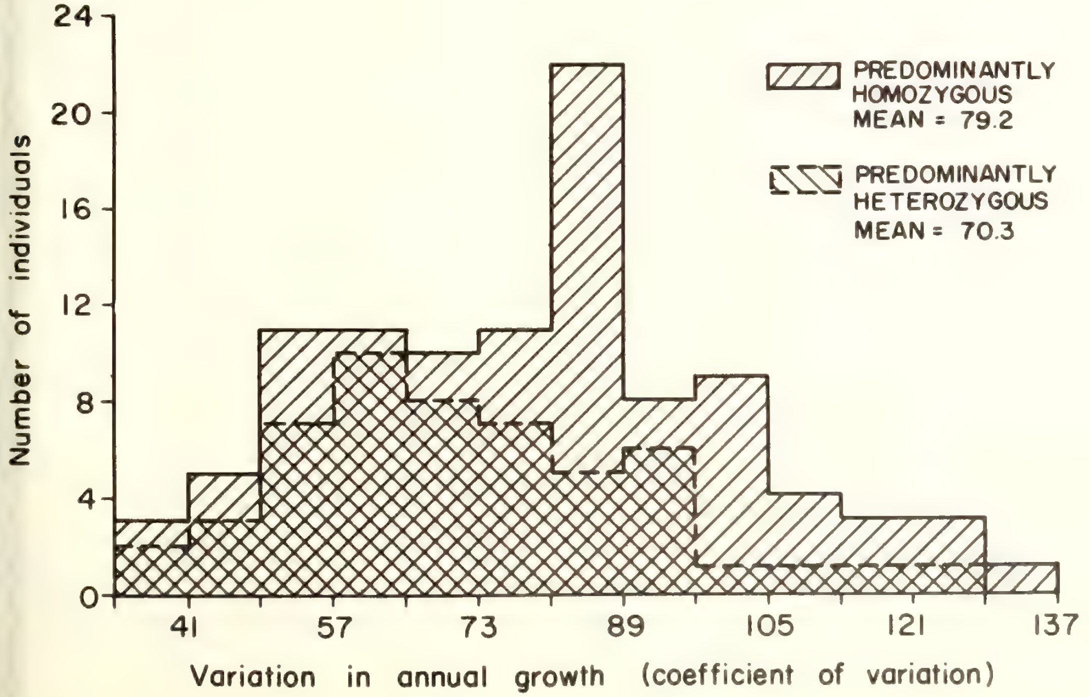

Figure 1—Distribution of the coefficients of variation in annual growth of the predominantly homozygous and predominantly heterozygous lodgepole pine trees (t = 2.52, P > 0.05).

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[5] Pierce, B. A., and J. B. Mitton. *Growth and heterozygosity in the tiger salamander, Ambystoma tigrinum.* (Manuscript submitted for publication.)

2) and ponderosa pine (*tables 3 and 4*), but lower growth variability in lodgepole pine (*fig. 1*). The sample sizes in each of the studies are substantial, so that we have confidence that the results are real. Although we have no simple, compelling hypothesis to explain the inconsistency, we offer the following possibility. As Lewontin (1956) cautioned, the inverse association between heterozygosity and phenotypic variation would only exist for those phenotypic characters that relate directly to the fitness of the organism. Is it possible that growth characteristics directly contribute to the fitness of lodgepole pine but not to that of ponderosa pine or aspen? Such a situation is doubtful. Rather, we would speculate that growth characteristics are one step removed from a more adaptively significant character, for example, reproductive output. We expect, all else being equal, that annual ring width and seed production are negatively correlated (Fritts 1976). Our measure of growth variability, therefore, may also contain considerable information about variation in seed production. Both quaking aspen and ponderosa pine are known to be highly variable in seed production from year to year (Linhart and others 1979, Linhart and others 1981, Marr 1961, Schubert 1974). Years of high seed production are scattered among more common years of low seed production. In contrast, the lodgepole pine in this study has predominantly serotinous cones, and yearly cone production is rather regular. Ponderosa pine and aspen may decrease their growth rates as a result of shunting energy into reproduction during years of heavy seed production. Lodgepole pine, however, may exhibit regular annual growth due to regular reproduction. If high heterozygosity is associated with the extreme of the frequency of reproduction typical for a given species, this could produce the observed association between heterozygosity and growth variability. This conjecture is offered tentatively with the intent of encouraging replication of these studies and initiation of new studies.

Another possible explanation for the discrepancy in direction of relationships between heterozygosity and growth variability is our use of different loci in the different species. If these loci play specific roles in controlling growth rate or growth variability, congruence may occur only when homologous loci are examined in each study.

The mechanisms that produce an association between level of heterozygosity and growth rate variables are of interest both theoretically and practically. Perhaps the first question that must be addressed in consideration of these mechanisms is: When individuals in a population are ranked or placed into groups on the basis of their heterozygosity at a few allozyme loci, just what is being measured? Heterozygosity at a few allozyme loci may estimate heterozygosity (a) of the whole genome, (b) of sections of the chromosomes tightly linked to the allozyme loci, (c) within one or several metabolic pathways, or (d) of only a few allozyme loci. A few loci can be used to reasonably reflect heterozygosity at one or a few dozen loci but it is unlikely that a few loci could accurately rank the members of a population by heterozygosity of the whole genome.[6] Perhaps the heterozygosity rankings used here are actually measuring heterozygosity in one of two major metabolic pathways (for example, pentose shunt, or dicarboxylic acid cycle). Heterozygosity levels within a pathway may provide more economic use of energy (Berger 1976), greater degrees of regulation (Johnson 1974), or efficiency for a greater range of temperature or of pH values (Fincham 1972, Gillespie and Langley 1974, Hochachko and Somero 1968). Different levels of heterozygosity within a major pathway could be reflected in growth variability measured from tree cores. Finally, the relationship between heterozygosity and growth rate variables could result solely from the specific loci being monitored. This possibility, however, is incompatible with the hypothesis that protein polymorphisms have little or no effect upon fitness (Kimura and Ohta 1971). A substantial number of kinetic studies of protein polymorphisms now indicate significant differences in *in vitro* performance of different genotypes at a locus (Beckman 1977; Day and others 1974a, 1974b; Merritt 1972; Miller and others 1975; Watt 1979) and these differences may reflect the performance of these genotypes in different environments.

Although the mechanisms for establishing relationships between heterozygosity and growth rate variables are unknown, much is to be gained from this type of study. If these relationships are general and reliable, they can be incorporated into tree improvement programs, because growth rate is likely to affect both quality and quantity of wood being produced. Finally, recent reviews have indicated that forest trees have higher levels of genetic variation than most other groups of animals and plants (Hamrick 1978, Hamrick and others 1979, Hamrick and others 1981). If the associations between heterozygosity and growth rate variables are general, and if differential growth rate and growth variability are adaptive, these associations may help us to understand why so much variation is maintained in forest trees. The influence of allozyme loci upon growth rate could be a fertile field for the joint efforts of geneticists and physiologists.

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Levels of Genetic Variation in Trees: Influence of life history characteristics[1]

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Abstract: In a previous study, levels of genetic variation, as measured by isozyme analyses, were compared for 113 taxa of vascular plants. Each species was classified for 12 life history and ecological traits and three measures of genetic variation were calculated. Plants with large ranges, high fecundities, an outcrossing mode of reproduction, wind pollination, a long generation time, and from habitats representing later stages of succession tended to have more isozyme variation than species with other combinations of characteristics. This paper discusses the results of the previous study and examines the available isozyme data for similar trends in forest trees. Special consideration was given to differences in genetic variation among 20 conifer species that have many of their life history characteristics in common. Successional stage, habitat type, cone type and historical events were associated with differences in genetic variation among the conifer species. These results are discussed in terms of expectations from current population genetics theory.

Forest trees have been the subject of many quantitative genetic investigations (Libby and others 1969, Stern and Roche 1974). These studies have concentrated on morphometric and physiological characteristics such as survival, growth initiation, height and diameter growth, hardiness to environmental stress, and various leaf, stem, fruit, and wood characteristics. As a result, the distribution of quantitative genetic variation is better understood in certain tree species than in most other naturally occurring plants.

Studies that use biochemical techniques to measure genetic variation in forest trees generally have lagged behind those that use quantitative traits. A few workers have used secondary plant compounds, such as terpenes, in studies of species (Zavarin and Snajberk 1969, Zavarin and others 1969), racial (Smith and others 1969) and population (Adams 1975a, 1975b) differentiation. But, because the genetic basis of variation in these compounds is poorly understood, they are of limited use in population genetic studies. Since the early 1970's, electrophoretic techniques have been used in genetic studies of forest tree populations. These techniques offer a number of advantages over other biochemical or quantitative approaches: (a) genetic inheritance of electrophoretically-detectable traits can be easily demonstrated; (b) most isozyme loci are codominant and gene frequencies can be calculated without the necessity of genetic crosses; (c) estimates of genetic variation can be compared directly between populations or between species. The relatively few isozyme studies of plant populations have been the subject of a number of recent reviews (Gottlieb 1977, Brown 1979, Hamrick 1979, Hamrick and others 1979). Generally, these reviews have concluded that plants contain somewhat more variation than invertebrate animals and considerably more variation than most vertebrates. Furthermore, different plant species contain varying amounts of genetic variation. Trees, for example, have been found to contain significantly more variation than herbaceous plants (Hamrick 1979, Hamrick and others 1979).

This paper reviews the results of a previous study (Hamrick and others 1979), which compared the isozyme variation of plant species with different combinations of life history traits and examines the available isozyme data for similar trends in forest trees. Specifically, we address the following questions:

- Do plant species with certain combinations of life history traits contain higher levels of genetic variation?
- Does being a woody plant directly affect levels of isozyme variation?
- Can differences in genetic variation among tree species be explained by their life history and ecological characteristics?

PROCEDURES

In a previous study (Hamrick and others 1979), we examined the relationship between 12 life history and ecological traits and the levels of genetic variation maintained within populations of 113 taxa of plants. Each species was classified for taxonomic status, geographic range, generation length, mode of reproduction, mating system, pollination mechanism, fecundity, seed dispersal mechanism, chromosome number, successional stage, habitat type, and cultivation status. Where the data allowed, three measures of intrapopulation genetic variation were calculated for each species: the percent of polymorphic loci per population (*P*), the mean number of alleles per locus (*A*), and a polymorphic index (*PI*). The *PI*

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Table 1—*Levels of variability among categories of 12 life history and ecological traits. Weighted means and standard errors are given for each measure of variability. Differences in* PI *between categories are tested by ANOVA. Statistical significance levels are given in parentheses (from Hamrick and others 1979)*

Variable	Species	Loci	Polymorphic loci (P)		Alleles per locus (A)		Polymorphic Index (PI)	
			$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.
			Percent					
Taxonomic status							($P<0.01$)	
Gymnospermae	11	9.2	67.01	7.99	2.12	0.20	0.270	0.041
Dicotyledoneae	74	11.4	31.28	3.31	1.46	.06	.113	.014
Monocotyledoneae	28	11.6	39.70	6.02	2.11	.19	.165	.026
Geographic range							($P<0.05$)	
Endemic	17	15.1	23.52	5.06	1.43	0.11	0.086	0.019
Narrow	22	11.4	36.73	6.01	1.60	.14	.158	.030
Regional	39	8.3	55.96	5.13	1.85	.10	.185	.025
Widespread	35	12.5	30.36	5.03	1.58	.15	.120	.021
Generation length							($P<0.001$)	
Annual	42	11.2	39.47	4.32	1.72	0.11	0.132	0.017
Biennial	13	17.2	15.78	5.12	1.26	.09	.060	.020
Short-lived perennial	31	12.0	28.09	5.06	1.46	.09	.123	.023
Long-lived perennial	27	7.6	65.77	5.08	2.07	0.13	0.267	0.027
Mode of reproduction							N.S.	
Asexual	1	8.0	50.00	0.00	1.91	0.00	0.139	0.000
Sexual	95	11.7	35.64	3.03	1.63	.07	.135	.012
Both	17	8.9	41.71	8.12	1.67	.14	.185	.034
Mating system							($P<0.01$)	
Primarily selfed	33	14.2	17.92	3.21	1.27	0.06	0.058	0.014
Mixed	42	8.6	14.16	4.89	1.76	.10	.181	.022
Primarily outcrossed	36	11.3	51.07	4.95	1.85	.12	.185	.022
Pollination mechanism							($P<0.001$)	
Selfed	33	14.2	18.99	3.51	1.31	0.07	0.058	0.028
Animal	55	9.5	38.83	3.94	1.55	.07	.130	.015
Wind	23	10.7	57.45	6.29	2.27	.17	.264	.028
Fecundity							($P<0.001$)	
$<10^2$	21	12.0	40.06	6.45	1.72	0.16	0.127	0.026
10^2 to 10^3	27	12.4	26.35	3.46	1.44	.07	.096	.013
10^3 to 10^4	22	11.9	36.98	6.37	1.64	.10	.199	.034
$>10^4$	40	9.8	67.99	5.99	2.27	.17	.286	.033
Seed dispersal mechanism							N.S.	
Large	27	11.4	37.42	3.73	1.76	0.16	0.156	0.023
Animal-attached	16	11.1	28.79	5.55	1.55	.08	.092	.020
Small	26	12.4	32.98	5.10	1.51	.09	.118	.018
Winged or plumose	21	12.2	44.91	7.27	1.86	.13	.188	.029
Animal ingested	20	7.0	32.98	8.25	1.43	.10	.132	.036
Chromosome number							($P<0.01$)	
10 to 20	50	13.1	35.52	3.61	1.55	0.08	0.111	0.014
22 to 30	44	10.0	37.41	5.35	1.73	.10	.175	.023
>30	16	8.9	41.65	7.20	2.10	.14	.224	.030
Stage of succession							($P<0.01$)	
Weedy and early	54	12.5	29.67	3.82	1.60	0.08	0.116	0.015
Middle	49	9.7	37.90	4.43	1.56	.08	.137	.019
Late	10	12.0	62.76	5.28	2.14	.19	.271	.038
Habitat type							N.S.	
Xeric	4	8.8	15.39	8.20	1.11	0.09	0.048	0.040
Submesic	19	10.5	43.68	4.86	1.66	.08	.140	.020
Mesic	82	11.4	36.01	3.61	1.65	.07	.146	.016
Hydric	8	13.0	27.71	10.33	1.59	.22	.145	.050
Cultivation status							N.S.	
Cultivated	21	6.8	38.99	7.15	1.61	0.12	0.172	0.032
Noncultivated	89	12.6	36.10	3.12	1.63	.07	.136	.013
Both	3	2.7	50.00	–	1.75	.21	.209	.035

is equivalent to the Hardy-Weinberg heterozygosity (Hamrick and Allard 1972).

For each category of the 12 life history variables weighted (by the number of loci), means were calculated for *P*, *A*, and *PI*, and mean *PI* values were compared for heterogeneity by single classification ANOVA. Multivariate statistics were used to determine correlations among traits and to test whether combinations of life history variables influence genetic variation. The data were analyzed first with a principal components analysis to describe the major patterns of covariation. Associations noted in this analysis were explored further with a stepwise multiple regression.

Differences in genetic variation among tree species was the subject of a second analysis. This analysis included studies not available earlier but was limited to studies that used a wide variety of enzyme systems. Values of *P*, *A*, and *PI* were calculated for each species and weighted means were calculated for each category of six variables. Multivariate analyses were not used since most of the tree species were conifers and, therefore, similar for many of their life history traits.

RESULTS

Isozyme Variation in Plants

The mean values of *P*, *A*, and *PI* obtained by pooling the 113 taxa in our original study were: $P = 36.8$ percent, $A = 1.69$, and $PI = 0.141$. When compared with animals, plants tend to have levels of genetic variation that are roughly equivalent to the invertebrates ($P = 46.9$ percent, $PI = 0.135$ [Selander 1976]; $P = 39.7$ percent, $PI = 0.112$ [Nevo 1978]) but are considerably higher than those of vertebrate species ($P = 24.7$ percent, $PI = 0.061$ [Selander 1976], $P = 17.3$ percent, $PI = 0.036$ [Nevo 1978]).

Genetic Variation and Life History Traits

Statistically significant differences ($P<0.05$) were found among categories of eight life history or ecological traits (*table 1*). Gymnosperm species tended to have more variation than angiosperms while regionally distributed species had more variation than those with other geographic ranges. We had expected species with the widest ranges to contain the most variation. Many species in this category, however, are weedy or early successional species that tend to have less variation. Long-lived perennials and plants with mixed or primarily outcrossed mating systems contained at least twice the variation of species in other categories. Within the outcrossed species, wind-pollinated species had more variation than those with animal pollination. Species with high fecundities and high chromosome numbers also had more variation as did species of the later stages of succession.

Multivariate techniques were used to identify groups of variables varying in concert, and to assess the covariation of genetic variation with ecological and life history variables. Approximately one-half of the correlations among the ecological, life history, and genetic variables were statistically significant. Pollination mechanism; mating system, and fecundity had the highest correlations with the genetic variables. Additional multivariate analyses demonstrated that only the first two principal components contributed to our understanding of the genetic variation among these species. The first principal component, which had high loadings from the three genetic variables, generation length, mating system, pollination mechanism, fecundity, seed dispersal and successional status explained 30 percent of the variation. The second principal component, which had high loadings from the genetic variables, taxonomic status, seed dispersal mechanisms, and successional stage explained 16 percent of the variation. These results were consistent with the univariate analyses and indicated that species with large ranges, high fecundities, an outcrossing mode of reproduction, wind pollination, a long generation time, and from habitats representing later stages of succession had more genetic variation than did species with other combinations of traits. It is worth noting that forest trees in general and conifers in particular combine many of the characteristics that are associated with high levels of genetic variation.

To determine which ecological and life history traits were most closely associated with genetic variation we employed a stepwise multiple regression analysis in which *PI* was the dependent variable and the 12 ecological and life history traits were independent variables. Only two variables were significant—pollination mechanism and fecundity. Species that are wind pollinated and highly fecund were the most genetically variable.

Variation Among Tree Species

The separate analyses of the tree data produced some noteworthy results. First, the mean level of variation within populations of coniferous trees was lower than that reported previously (Hamrick and others 1979). In the earlier review (Hamrick and others 1979), the inclusion of studies based solely on polymorphic loci tended to increase estimates of the mean levels of variation. Also, many of the earlier tree studies used enzyme systems such as esterases and peroxidases that are often highly variable. The data in the present analyses are relatively free of these biases and should be more representative of the actual levels of genetic variation in tree populations. It is significant, therefore, that the mean levels of variation in tree populations continue to exceed that of herbaceous species by more than 60 percent.

A second important result is the continued observation of interspecific differences in genetic variation. The *PI* varies from 0.000 for red pine (*Pinus resinosa* Ait.) to 0.364

Table 2 *Summary of electrophoretic studies of genetic variation in trees. P = percent of polymorphic loci, A = alleles per locus, PI = polymorphic index*

Species[1]	Location	Loci	Populations	*P*	*A*	*PI*	Source
				A. Gymnosperms			
Abies balsamea	New Hampshire	14	1	64.0	1.86	0.150	Neale (1978)
Picea abies	Sweden	12	4	91.7	3.54	.341	Lundkvist (1979)
P. sitchensis	Rangewide	24	10	–	1.90	.150	Yeh, F. (unpubl.)
Pinus aristata	Rangewide	22	5	46.4	1.55	.139	Hiebert, R.D. and Hamrick, J.L. (unpubl.)
P. attenuata	Rangewide	22	10	73.0	2.09	.140	Conkle, M.T. (unpubl.)
P. balfouriana	Rangewide	23	4	57.6	1.61	.208	Hiebert, R.D. and Hamrick, J.L. (Unpubl.)
P. banksiana	Michigan	21	1	28.6	–	.083	Snyder, T. (unpubl.)
P. contorta	British Columbia	27	17	–	1.90	.150	Yeh, F. (unpubl.)
P. contorta	California	37	1	89.2	2.78	.190	Conkle, M.T. (unpubl.)
P. contorta	Colorado	26	1	42.0	1.42	.160	Hamrick, J.L. (unpubl.)
P. lambertiana	Rangewide	20	–	80.0	2.85	.260	Conkle, M.T. (unpubl.)
P. longaeva	Rangewide	14	5	78.6	2.35	.364	Hiebert (1977)
P. jefferyi	California	44	1	–	2.90	.260	Conkle, M.T. (unpubl.)
P. muricata	Northern California	17	1	65.0	1.53	.090	Millar, C. (unpubl.)
P. ponderosa	Eastern Colorado	22	7	68.4	2.00	.226	Hamrick, J.L. (unpubl.)
P. pungens	Rangewide	15	3	40.0	1.33	.144	Feret (1974)
P. resinosa	Rangewide	9	5	0.0	1.00	.000	Fowler and Morris (1977)
P. rigida	Rangewide	21	11	78.8	2.19	.144	Guries, R. and Ledig, T. (unpubl.)
P. strobus	Seed Orchard, New Hampshire	17	–	52.9	2.06	.330	Eckert and others (1980)
P. taeda	North Carolina	11	1	100.0	3.73	.240	Conkle, M.T. (unpubl.)
P. taeda	Superior Trees	30	–	93.3	3.87	.260	Conkle, M.T. (unpubl.)
P. taeda	Seed Orchard, South Carolina	15	–	80.0	2.93	.200	Adams and Joly[2]
Pseudotsuga menziesii	British Columbia, Interior	21	11	–	2.23	.180	Yeh, F. (unpubl.)
P. menziesii	Coastal	21	11		2.23	.150	Yeh, F. (unpubl.)
P. menziesii	California Coastal	11	9	74.2	3.17	.332	Morris, R. (unpubl.)
P. menziesii	California Interior	17	1	100.0	1.78	.330	Conkle, M.T. (unpubl.)
P. menziesii	Eastern Colorado	22	5	64.0	1.86	.264	Hamrick, J.L. (unpubl.)
Sequoiadendron giganteum	Rangewide	8	34	50.0	2.63	.155	Fins, L. (unpubl.)
	Mean	20.1	–	67.7 ±4.9	2.29 ±0.14	.207 ±.017	
				B. Angiosperms			
Persea americana cultivars		10	–	80.0	1.90	.195	Torres and others (1978)
Phoenix dactylifera cultivars		7	–	100.0	2.00	.332	Torres, A.M. (unpubl.)
	Mean	8.5	–	88.23 ±10.0	1.94 ±0.05	.251 ±.028	

[1] Only those studies that used a variety of enzyme systems are included.

[2] Adams, W.T., and R.J. Joly. Allozyme studies in loblolly pine seed orchards: clonal variation and frequency of progeny due to self-fertilization. (Manuscript in preparation.)

for Great Basin bristlecone pine (*P. longaeva* D.K. Bailey). Since the 20 conifer species have many of their life history characteristics in common, only six traits were available to explain the differences in genetic variation observed among species—taxonomic status, geographic range, stage of succession, habitat type, cone type, and U.S. distribution.

The present data (*table 2*) are inadequate to determine whether differences between angiosperm and gymnosperm trees were significant. The two studies of angiosperm trees that met our criteria involved commercial cultivars of fruit trees. Although angiosperm trees appear to have as much genetic variation as conifers, final conclusions must await studies of naturally occurring angiosperm trees.

The geographic range of each conifer was classified as endemic, narrow, or regional (*table 3*). Most species had a regional distribution with only foxtail pine (*Pinus balfouriana* Grev. & Balf.) and giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) classified as endemics. The differences in *PI* between these categories were small and were not significant ($P < 0.50$).

The ability of a species to successfully reproduce in its own shade and in the absence of environmental disturbance was used to classify the species into one of

Table 3–*Levels of variability among categories of five life history and ecological variables for 28 conifer studies. Weighted means and standard errors are given. Differences in* PI *between categories are tested by ANOVA. Significance levels are indicated in parentheses*

Variable	Species[1]	Studies	Mean loci	Polymorphic Index (*PI*)	
				Mean	*S.E.*
Geographic range				($P < 0.50$)	
Endemic	2	2	15.5	0.194	0.052
Narrow	8	8	22.2	.197	.032
Regional	10	18	19.7	.207	.023
Stage of succession				($P < 0.10$)	
Early	7	10	19.9	0.161	0.030
Middle	7	11	19.8	.241	.022
Late	7	7	20.8	.204	.035
Habitat type				($P < 0.10$)	
Xeric	3	3	19.3	0.194	0.075
Submesic	11	15	21.7	.186	.021
Mesic	6	10	17.9	.238	.026
Cone type				($P < 0.01$)	
Closed cone	6	7	21.3	0.132	0.012
Open cone	15	21	20.4	.226	.020
United States distribution				($P < 0.30$)	
Northeastern	5	5	16.4	0.152	0.054
Southern	2	4	17.8	.235	.042
Western	12	18	22.1	.204	.018

[1] Some species may be represented in more than one category.

three stages of succession (*table 3*). More variation (P < 0.10) was observed in populations of middle and late successional species and less in populations of pioneering species. Only the presence of loblolly pine (*P. taeda* L.) in the early category prevented the results from being statistically significant.

Differences among the habitat categories approached statistical significance (P < 0.10), but no definite trend can be seen (*table 3*). Differences between the submesic and mesic categories suggest a pattern but with only two species in the xeric category no definite conclusions can be drawn. Studies of genetic variation in conifer species that are adapted to drought conditions, such as the piñon pines and junipers, should yield valuable information on this question.

Species with closed cones or ecotypes of species that have closed cones were grouped together. These species had significantly less variation (P<0.01) than open-coned species (*table 3*).

Species which inhabit different geographic regions within the United States may also have different levels of genetic variation. The northeastern species (*Abies balsamea* [L.] Mill., *Pinus banksiana* Lamb., *P. resinosa* Ait., *P. rigida* Mill., and *P. strobus* L.) have somewhat less variation (P < 0.30) while the southern (*Pinus taeda* L. and *P. pugens* Lamb.) and the western species have higher values.

To summarize the results of the analyses on trees, species of later successional stages, mesic habitat types, with open cones and a southern or western distribution have more genetic variation than species with alternate combinatons of characteristics.

DISCUSSION

A significant proportion of the differences in genetic variation among plant species is accounted for by variation in their life history and ecological characteristics. Species with large ranges, high fecundities, an outcrossing mode of reproduction, wind pollination, a long generation time and from habitats representing later stages of succession have higher amounts of genetic variation. This result is generally consistent with that predicted by population genetics theory. Plants, in general, might be expected to maintain high levels of genetic variation within their populations since their sessile nature often leads to the evolution of locally adapted ecotypes (Antonovics 1971, Bradshaw 1972, Jain and Bradshaw 1966). Also, long-lived plant species with large ranges and high fecundities typically have large, stable populations. Such populations are resistant to chance fluctuations in gene or genotype frequencies and should maintain more variation than populations that experience large fluctuations in size. Longevity also ensures the representation of many cohorts within a population. If different alleles or genotypes are favored during the establishment phase of each cohort, individuals that survive to maturity will maintain a genetic "record" of these evolutionary events. Their continued survival would retard the loss of genetic variation. Greater longevity could be especially effective in maintaining genetic variation in later stages of succession because individuals are continuously becoming established in a highly complex biotic environment. It should be noted, however, that the seed carryover abilities of many annuals and short-lived perennials could produce a similar genetic record. Finally, high rates of fecundity, outcrossing and wind pollination ensure large neighborhood sizes and the production of a variety of genotypes through recombination. Natural selection could act to maintain this variation through the evolution of locally adapted ecotypes or through various types of balancing selection.

The existence of high levels of genetic variation in forest tree populations can be explained primarily by their life history and ecological characteristics. The question remains, however, of whether woodiness has a direct effect on the levels of genetic variation that are maintained. Current evidence, although scanty, indicates that herbaceous species with life history or ecological traits similar to those of trees also have high levels of genetic variation. This would argue against woodiness itself as affecting the maintenance of genetic variation. An alternate argument can be made on the basis of differences in life forms (Raunkiaer 1934) between woody and herbaceous plants (Hamrick 1979). Woody plants are phanerophytes and maintain their apical meristems above ground. Their apical meristems, therefore, are exposed to environmental fluctuations throughout the year. Herbaceous perennials are either chamaephytes, hemicryptophytes or cryptophytes whose apical meristems are located at or below the soil surface during periods of severe environmental stress. The moderating effects of snow, soil, or litter cover may, in essence, reduce selection pressures for the internal buffering thought to be produced by increased heterozygosity (Lerner 1954). If this argument is valid we would expect to find differences in genetic variation between populations of herbaceous and woody plants that occur in the same habitats and have similar life history traits. Also, we would expect to find an increase in heterozygosity in older age classes and in temporally fluctuating environments. An increase in heterozygosity in older age classes was demonstrated in a population of *Liatris cylindracea* Michx. (Schaal and Levin 1976). A further test of this argument would be provided by surveying a wider variety of woody trees and shrubs.

Differences in genetic variation among the conifer species surveyed are somewhat more difficult to explain. This is because the 20 conifer species have many of their life history characteristics in common. Although only one of the six traits — cone type — was statistically significant, geographic range was the only trait that failed to have large differences among the mean *PI* values. This result is not surprising since endemic and narrowly distributed tree species often have rather large population sizes where they occur. Also both of the endemic species, *Pinus balfouriana* Grew. & Balf. and *Sequoiadendron giganteum* (Lindl.) Buchholz, are long-lived and could maintain genetic variation by this mechanism.

Trends observed for stage of succession, habitat type, and cone type in the conifer data are generally consistent with previous results (Hamrick and others 1979); conifers from mid- and late-successional stages, mesic habitats, and with open cones tend to have higher levels of genetic variation. Trees of early successional stages must adapt to relatively homogeneous environmental conditions that are influenced primarily by physical factors. Coupled with their colonizing habit, such uniform selection pressures might lead to a reduction in genetic variation. As succession proceeds, the biotic environment becomes increasingly important and, as a result, habitats become more complex and heterogeneous. Such complex environments may select for the maintenance of higher levels of genetic variation. A similar explanation may apply to the higher levels of variation observed in the more mesic adapted trees.

The lower levels of variation found in the closed-cone pines could result from a combination of factors. First, the closed-cone species are adapted to habitats which experience periodic catastrophic wildfires and are, therefore, almost always members of early successional communities. Such species germinate and grow under relatively uniform environmental conditions. Also, the closed cone habit and short life expectancy ensures even-aged stands. The genetic record of the long-lived, uneven aged species is not, therefore, an important factor in the maintenance of genetic variation in closed-cone species.

The geographic region to which conifer species are native also seems to affect genetic variation. Four of the five northeastern conifers maintain less variation than their southern and western counterparts. Two factors may help to explain this observation. First, it could be argued that western habitats are environmentally more heterogeneous than those in the northeast. Support for this argument comes from the greater diversity of community types in the West (Küchler 1964). The high variation in the two southern species contradicts this argument, however. A second factor to consider is the evolutionary history of each species. The northeastern species have been exposed to numerous continental glacial events. Glaciation may have greatly reduced the ranges of the northeastern species and reduced population sizes and genetic variation. Although the western species have also been exposed to changes in climatic factors and shifts in their ranges, the more varied topography of the West may have provided a greater variety of refugia. In fact, some of the western species expanded their ranges during glacial periods (for example, *Pinus longaeva* D.K. Bailey[4]).

In conclusion, a thorough knowledge of a species' life history and ecological characteristics is essential if its genetic structure is to be understood. Much of the heterogeneity in genetic variation seen among species can e explained by such considerations. A significant amount f unexplained heterogeneity remains, however. Past istorical events and characteristics which have not been onsidered may partially explain the differences that emain. As additional plant species are studied we should ain a clearer understanding of the role that life history haracteristics, or combinations of characteristics, play in haping the genetic structure of plant populations, ncluding those of forest trees.

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[4] Personal communication from P.V. Wells.

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Genetic Structure of Populations and Differentiation in Forest Trees[1]

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Abstract: Electrophoretic techniques permit population biologists to analyze genetic structure of natural populations by using large numbers of allozyme loci. Several methods of analysis have been applied to allozyme data, including chi-square contingency tests, F-statistics, and genetic distance. This paper compares such statistics for pitch pine (*Pinus rigida* Mill.) with those gathered for other plants and animals. On the basis of these comparisons, we conclude that pitch pine shows significant differentiation across its range, but appears to be less differentiated than many other organisms. Data for other forest trees indicate that they, in general, conform to the pitch pine model. An open breeding system and a long life cycle probably are responsible for the limited differentiation observed in forest trees. These conclusions pertain only to variation at allozyme loci, a class that may be predominantly neutral with respect to adaptation, although gene frequencies for some loci were correlated with climatic variables.

During the last 40 years, a considerable body of information has been assembled on genetic variability in forest tree species. Measurements of growth rate, cold-hardiness, phenology, and related traits have provided tree breeders with much useful knowledge, and have indicated in a general way how tree species have adapted to a spatially variable habitat (Wright 1976). Most information has come from studies designed to assess relative differences in metric traits among provenances representing a wide geographic range. When the identification of suitable seed sources for use in reforestation is a primary objective, provenance tests (that is, common garden studies) may be indispensible. However, such studies are expensive to conduct, require large areas of land, yield useful data only after many years, and use traits of unknown inheritance.

The development of electrophoretic techniques during the last two decades provided an alternative to common garden techniques for estimating levels of genetic variation in natural populations (Lewontin 1974). Electrophoretic techniques are now widely used in studies of plant and animal populations and have produced a large body of data on the levels and patterns of genic variability characteristic of many species. Although the difficulties inherent in the large size and late reproductive maturity of trees somewhat delayed their study, there is in recent years a rapid accumulation of useful data from the application of electrophoretic techniques to several conifers.

POPULATION STRUCTURE

A common notion among foresters is that most tree species are divided into relatively small breeding populations because of limited pollen or seed dispersal. Most matings are considered to be among near neighbors, leading in time to the division of a large population into numerous, small "neighborhoods." Other factors such as physical isolation, breeding system, population demography, natural selection, and random genetic drift accentuate such subdivision. The sum total of the ecological and genetic relationships among individuals and the populations they comprise is termed "population structure" (Jain 1975).

Of special interest to tree breeders are the genetic consequences of population structure. Several measures of the genetic structure of populations have been proposed, including assessments of (a) gene diversity in the average population, (b) levels of diversity in different populations, and (c) degree of differentiation among populations (Brown 1978). All these measures are amenable to allozyme analysis, and recent explorations have begun to probe the genetic structure of forest trees.

Our approach in this paper is to compare estimates of various parameters of population structure obtained from pitch pine (*Pinus rigida* Mill.) with those of other species. Rigorous comparisons are seldom possible because of variation in methods of data collection and analysis; therefore, we use them here only for purposes of general description.

CHI-SQUARE ANALYSIS OF HETEROGENEITY

The subdivision of populations may lead to a heterogeneity of gene frequencies among subpopulations as a result of selection or drift. Variation in genic proportions ın be subjected to a contingency chi-square analysis to etermine the existence or extent of any heterogeneity Workman and Niswander 1970). A major advantage of ıe technique is ease of calculation; however, the analysis oes not identify the forces responsible for any observed eterogeneity. For pitch pine, chi-square was calculated sing the technique of Snedecor and Irwin (1933):

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$$\chi^2 = 2N \sum_i \sigma^2_{p_i}/\bar{p}_i,$$

ı which N is the total number of individuals, $\sigma^2_{p_i}$ is the ıriance in allele frequency, and $\bar{p}_i$ is the weighted mean equency.

A significant amount of heterogeneity is apparent at ıost of 21 loci in 11 populations of pitch pine (*table 1*). onsidering the wide range over which pitch pine samples ere collected (from Quebec to North Carolina), differen- al selection in varying environments is one possible xplanation. Distribution of allele frequencies was ob- rved to be heterogeneous over relatively short distances ı ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), erhaps because of differential selection on slopes of ırying aspect (Mitton and others 1977). However, Neale 978) found no evidence of allelic heterogeneity among opulations of balsam fir (*Abies balsamea* [L.] Mill.) ccurring along an elevational gradient in New Hamp- ıire, although differences in growth and physiological rocesses were observed and related to environmental ıriation along the same transect (Fryer and Ledig 1972).

Genetic drift could also produce heterogeneity. In pitch ıne, certain populations (for example, one in St. Chrysostome, Quebec) are isolated from the main body of the species range. If such populations were founded by a small number of individuals, genetic drift could account for much of the observed heterogeneity. Genetic drift was a possible explanation for observed heterogeneity of gene frequencies among three small populations of Table Mountain pine (*Pinus pungens* Lamb.) in Virginia (Feret 1974). In any event, the large range in chi-square values among loci in pitch pine suggests that different loci are probably responding independently to whatever factors are responsible for the heterogeneity.

Table 1—*Chi-square contingency analysis of gene frequency heterogeneity by locus for 11 pitch pine populations*

Locus	χ^2	df	P<
MDH-1	45.76	10	0.005
MDH-2	107.77	10	.005
IDH	95.43	10	.005
FUM	18.22	10	.1
PGM-1	9.39	10	.5
PGM-2	42.22	10	.005
GPI-1	16.60	10	.1
GPI-2	28.07	10	.005
6-PGD-1	166.36	10	.005
6-PGD-2	52.58	10	.005
G-6-P	39.66	10	.005
LAP-1	51.91	10	.005
LAP-2	37.97	10	.005
GOT-1	44.39	10	.005
GOT-2	34.59	10	.005
ACP	54.92	10	.005
ACO	131.04	10	.005
GDH	31.72	10	.005
ADH	3.64	10	.95
ALD-1	30.00	10	.005
ALD-2	148.57	10	.005

F-STATISTIC ANALYSIS OF POPULATION STRUCTURE

The structure of a subdivided population can also be analyzed by F-statistics (Wright 1951, 1965, 1969; Kirby 1975; Nei 1977). F-statistics were originally devised to examine structuring in hierarchical populations by using the correlation between uniting gametes within and among subpopulations and for the population as a whole. Wright (1965) advanced three parameters "in terms of a total population (T), subdivisions (S), and individuals (I). F_{IT} is the correlation between gametes that unite to produce the individuals, relative to the gametes of the total population. F_{IS} is the average overall subdivisions of the correlation between uniting gametes relative to those of their subdivision. F_{ST} is the correlation between random gametes within subdivisions, relative to gametes of the total population. The list can be extended if there are further subdivisions. The above three F-statistics are not independent."

These statistics have as a common focal point the fixation index, F, which represents the total deviation from Hardy-Weinberg proportions because of the joint effects of finite population size, selection, inbreeding, and other factors. The estimate of F_{IS_i} for the ith subpopulation was calculated as:

$$F_{IS_i} = 1 - H_i / \frac{1}{(1+2N_i-1)} \; 2\, p_i\, q_i$$

in which H_i is the observed number of heterozygotes in the ith subpopulation and the denominator is the expected number corrected for finite population size (Kirby 1975).

F_{IS} represents the average deviation of the population's genotypic proportions from Hardy-Weinberg equilibrium for a locus and is calculated as the weighted mean of the F values for all populations;

$$\hat{F}_{IS} = \sum_i \frac{N_i}{N} p_i q_i F_{IS_i} / \sum_i \frac{N_i}{N} p_i q_i .$$

A negative F_{IS} value represents an excess of heterozygotes. It is worth noting that F_{IS} is not equivalent to the coefficient of inbreeding except in the unlikely event that inbreeding alone is responsible for departures from Hardy-Weinberg equilibrium. F_{IS} can be averaged across all loci.

The extent of differentiation among subpopulations is measured by F_{ST}, the correlation between random gametes within subdivisions, and was calculated as Nei's (1975) G_{ST}:

$$G_{ST} = D_{ST}/H_T,$$

in which H_T is the gene diversity in the total population, D_{ST} is the average gene diversity among subpopulations.

$$H_T = 1 - \sum_k (\sum_i p_{ik}/S)^2, \text{ and}$$

$$D_{ST} = \sum_i (\sum_k p_{ik}^2) - \sum_k (\sum_i p_{ik}/S)^2.$$

in which p_{ik} is the frequency of the k^{th} allele in the i^{th} subpopulation and S is the number of subpopulations.

For gene loci with only two alleles, F_{ST} was also calculated as:

$$F_{ST} = \sigma_p^2/\bar{p}\,\bar{q},$$

in which σ_p^2 is the weighted sum of squared deviations of the individual subpopulation gene frequencies from the mean gene frequency, divided by the number of subpopulations, and $\bar{p}$ and $\bar{q}$ represent weighted mean frequencies.

F_{ST} was extended to multiple allele systems by Nei (1965):

$$F_{ST} = -\sigma_{jk}/\bar{p}_j \bar{p}_k,$$

in which

$$\sigma_{jk} = \sum_i \frac{N_i}{N} (p_{ji} - \bar{p}_j)(p_{ki} - \bar{p}_k),$$

$$\bar{p}_j = \sum_i \frac{N_i}{N} p_{ji}, \text{ and}$$

$$\bar{p}_k = \sum_i \frac{N_i}{N} p_{ki},$$

where p_{ji} and p_{ki} are the j^{th} and k^{th} alleles in the i^{th} population. F_{ST} for multiple alleles must be calculated for each combination of alleles. For pitch pine, differences between Nei's G_{ST} and Wright's F_{ST} were negligible, and Nei's calculation was preferred.

The overall fixation index, F_{IT}, represents the correlation between uniting gametes relative to the gametes of the total population and was calculated from F_{IS} and F_{ST} as:

$$F_{IT} = F_{IS} + (1 - F_{IS}) F_{ST}.$$

Like F_{IS}, F_{IT} may be positive or negative, with a negative value indicative of excess heterozygotes. If all populations are in Hardy-Weinberg equilibrium, $F_{IS} = 0$ and $F_{IT} = F_{ST}$. However, even if Hardy-Weinberg proportions are obtained, differentiation because of differing allele frequencies in subpopulations can lead to significant F_{ST} and F_{IT} values.

F-statistics are arranged by increasing F_{ST} values for several species of plants and animals including human populations in *table 2.* Two species of trees, pitch pine and balsam fir, for which estimates are included in *table 2,* were both characterized by relatively small F_{IS} values, an indication that populations are at or near Hardy-Weinberg equilibrium. This may or may not indicate that inbreeding is insignificant, because a tendency toward increasing F_{IS} values by way of inbreeding could be offset by such factors as migration or differential fertility. In fact, opposing forces probably counter-balance each other in many instances, with the net result that F (and, therefore, F_{IS}) is near zero (Workman 1969).

For both tree species, F_{ST} values were also small, relative to other organisms. Balsam fir, which did not show allelic heterogeneity in contingency chi-square tests (Neale 1978), has a value of F_{ST} about one-half as large as pitch pine. However, the range sampled in pitch pine was much larger, more than 1000 km in both north-south and east-west directions, while balsam fir was sampled on a single mountainside. F_{ST} values have been calculated for a variety of other organisms not given in *table 2,* but including the house mouse (F_{ST} = 0.024, one barn; Selander 1970), *Drosophila robusta* (F_{ST} = 0.055, Eastern United States; Prakash 1973), and the brown snail (F_{ST} = 0.116, a city

Table 2—*F-statistics from plant, animal, and human populations*

Groups of plant, animal, and human populations	Loci	F_{IS}	F_{ST}	F_{IT}	Sampling unit	Source
Japanese	1	0.002	0.001	0.003	All Japan	Nei and Imaizumi 1966
Monarch butterfly	6	.008	.009	.017	Eastern United States	Eanes and Koehn 1978
Balsam fir	7	.001	.012	.013	New Hampshire mountainside	Neale 1978
Papago Indians	7	−.005	.023	.009	10 reservation districts	Workman and Niswander 1970
Pitch pine	21	.009	.024	.034	Eastern United States	Guries and Ledig (in preparation)
Bluegill	3	.012	.029	.024	Within reservoirs	Avise and Felley 1979
Yanomama Indians	8	.022	.064	.045	37 villages in Venezuela	Neel and Ward 1972
Cylindric blazing-star	15	.407	.069	.426	1/8 acre	Schaal 1975
Phlox (3 species)	4 to 6	.503	.200	.643	Central Texas	Levin 1978

lock; Selander and Kaufman 1975). Geographic differen-
iation for pitch pine across its range is roughly no larger
han that observed among bluegill populations within a
ingle lake or Indian settlements on a single Indian
eservation. The estimates for pitch pine are considerably
maller than those obtained for brown snails within the
arrow confines of a city block or the herbaceous plant,
ylindric blazing-star (*Liatris cylindracea* Michx.), grow-
ng on a plot of only 1/8-acre. Although population dif-
erentiation has occurred in pitch pine as indicated by the
hi-square contingency test, it has not developed to the
egree characteristic of many other organisms.

As a result of a low fixation index within populations
ow F_{IS}) and a lack of extensive differentiation among
opulations (low F_{ST}), the total fixation index, F_{IT}, in pitch
ine is also low. The two estimates for herbaceous plants
ncluded in *table 2* have F_{IT} values from 10 to 20 times
reater than pitch pine, a feature probably indicative of a
igh degree of inbreeding in the herbs.

NALYSIS OF GENETIC DISTANCE

Perhaps the most widely applied index of genetic
ifferentiation is that of genetic distance (Nei 1972). This
ethod was developed to use isozyme data as a measure of
e accumulated number of gene substitutions per locus
nd is defined by:

$$D = -\log_e I$$

n which I represents the normalized identity of genes. If
wo populations have the same alleles in the same fre-
uency, I = 1; when two populations have no alleles in
ommon, I = 0.

Estimates of genetic distance among populations within
species (or among species) are available for a number of
lants and animals (see reviews of Avise 1974, Gottlieb
977). Estimates of the mean genetic distance among
onspecific populations for a number of species indicate
at divergence among populations of tree species has been
ather limited relative to that found in other organisms
ver much smaller areas (*table 3*). Results are consistent with F_{ST} values presented earlier. It should be noted that all tree species for which such estimates are available are outbreeding and anemophilous, and gene flow may be substantially greater than for trees that use animals as pollen vectors.

Comparisons of genetic distance with geographic distance have frequently been useful in determining whether differentiation can be explained on the basis of isolation by distance. For example, genetic distance in cylindric blazing-star (*table 2*) was strongly correlated with geographic distance and "neighborhoods" became well-differentiated over distances of several meters (Schaal 1974).

To test whether a significant relationship exists between genetic and geographic distance for populations of pitch pine, a product-moment correlation was calculated and proved to be nonsignificant ($r = 0.263$; $0.1 > P > 0.05$). By contrast, a significant correlation was noted between genetic and geographic distance for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) populations in coastal British Columbia.[4] However, it appears that much of the differentiation observed in Douglas-fir was the result of differences between island and mainland populations.[5]

RELATIONSHIP TO ENVIRONMENTAL GRADIENTS

Geographic distance *per se* may not be the most useful parameter by which to measure isolation, especially if the loci in question are under selection pressure. Therefore, product-moment correlations between the frequency of the most common allele and several climatic variables were calculated for the 11 most polymorphic loci in pitch pine (*table 4*).

Significant correlations were noted for six of the 11 loci. Although such correlations are not evidence for the operation of natural selection, they parallel clinal patterns

Table 3—*Mean genetic distance estimates, $\bar{D}$, for a number of species and sampling units with estimates arranged in order of increasing $\bar{D}$*

Species	Loci	$\bar{D}$	Sampling unit	Source
Douglas-fir	21	0.004	Coastal British Columbia	Yeh and O'Malley (in preparation)
Pitch pine	21	.007	Eastern United States	Guries and Ledig (in preparation)
Silver spot butterfly	3	.013	Northern California	Brittnacher and others 1978
Norway spruce	4	.014	Sweden	Lundkvist and Rudin 1977
House mouse	41	.014	Single barn	Selander, Hunt and Young 1969 (see Nei 1972)
Phlox	20	.019	Central Texas	Levin 1978
Mosquitos	18	.042	Coastal Kenya	Tabachnick and others 1979
American Indian tribes	6	.053	Northern South America	Ward and others 1975
Topminnow	25	.119	Northwestern Mexico	Vrijenhoek and others 1977
Pocket gophers	23	.144	Southwestern United States	Patton and Yang 1977
Newts	35 to 40	.292	River drainage in California	Hedgecock 1978

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[4] Yeh, F.C., and D. M. O'Malley. Enzyme variations in natural populations of Douglas-fir (*Pseudotsuga menziessi* [Mirb.] Franco) from British Columbia. Ms. submitted to *Silvae Genetica*.

[5] Personal communication from D. M. O'Malley, University of Wisconsin, Madison, July 1979.

Table 4–*Product-moment correlations between frequency of most common allele for 11 loci in pitch pine and selected climatic variables*

Climatic variable[1]	Locus[2]										
	MDH-1	MDH-2	IDH	6-PG-1	6-PG-2	G-6-P	LAP-1	LAP-2	GOT-1	GOT-2	ACO
Min. Jan. temp.	–0.06	0.406	0.655*	–0.718**	–0.367	–0.743**	–0.12	0.275	–0.776**	0.131	–0.502
Max. July temp.	.514	–.19	.432	–.342	.175	–.002	.139	.675	.036	–.257	.228
Heating ° days	–.18	–.577*	–.664*	.693*	.272	.734**	.095	–.477	.693*	.333	.333
Annual precipitation	–.042	.557	.453	–.401	–.463	–.772**	–.743**	–.181	–.514	–.344	–.441
Total snowfall	–.150	–.588*	.440	.687*	.338	.779**	.191	–.279	.721**	–.048	.292

[1] Source: 30-year climatic data summaries from NOAA Environmental Data Service (1979).

[2] *Statistically significant at 5 percent level.

**Statistically significant at 1 percent level.

of phenotypic variation noted in wood specific gravity (Ledig and others 1975) and cone serotiny (Ledig and Fryer 1972), and genetic variation in height growth revealed in a common garden study (Ledig and others 1976). In all of these studies patterns of variation were well correlated with ecological variables considered important to growth or survival. In the present study, for four of six loci, significant correlations between allele frequencies and climatic variables involved winter temperature or snowfall, which perhaps, reflect environmental stress; conditions which tend to reduce survival and limit reproductive rate in pitch pine.

DISCUSSION

The overall picture of pitch pine emerging from these analyses is one of a weakly differentiated series of populations. Although isolation by distance appears to be an important aspect of differentiation in herbaceous plant species, it is only mildly so in pitch pine. The lack of significant barriers to gene flow may be one important reason for the relatively undifferentiated status of pitch pine with regard to allozyme loci. Although the range of pitch pine includes disjunct populations, no major geographic barriers to gene flow exist, and the time since pitch pine migrated from its glacial refugium to occupy its present range has been brief, less than 100 to 300 generations. Furthermore, pitch pine, like most north-temperate tree species, is anemophilous, and wind can be an effective pollen vector for long distance transport (Koski 1970). In addition, pitch pine shows a dramatic depression when subjected to inbreeding (Wright 1962); therefore, selection reduces the impact of inbreeding and favors a strong tendency to outbreeding. For genetic distance, the estimates for pitch pine and other tree species (*table 3*) are similar and smaller than similar comparisons with inbreeding herbaceous species. The characteristic long generations and open breeding systems shared by tree species may act to distinguish them from herbaceous species.

Nevertheless, the data are insufficient to determine whether the results observed for pitch pine are really typical of other forest trees. Our current opinion is that they will prove to be reasonably typical of many other eastern conifers. Similarities in breeding system, demography, range, time since post-Pleistocene recolonization, and other factors all suggest that patterns paralleling that of pitch pine might be expected. Conifers such as eastern hemlock (*Tsuga canadensis* [L.] Carr.), which is a late successional species, red pine (*Pinus resinosa* Ait.), which has limited genetic variability (Fowler and Morris 1977), or jack pine (*Pinus banksiana* Lamb.) with an extensive range, may differ from the pitch pine model. Conifers of the Western United States may be relatively more differentiated than pitch pine, especially those that have extensive and fractionated populations in mountainous areas where opportunities for differential selection are great. In mountainous areas population structure in its spatial aspects conforms to an island model, and is conducive to differentiation among populations. Some hardwoods, those that are insect-pollinated, may also deviate considerably from the pitch pine model, but most anemophilous hardwoods should parallel pitch pine. Electrophoretic studies of these and other species will undoubtedly increase our knowledge of the genetic structure and differentiation characteristic of forest trees. Results from such studies should be of great interest and value to population biologists and tree breeders alike.

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Analyses of Gene Diversity in Some Species of Conifers[1]

Francis C. Yeh[2]

Abstract: Genetic variation at 21 to 25 loci in extracts of individual megagametophytes was surveyed in Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), Sitka spruce (*Picea sitchensis* [Bong.] Carr.) and lodgepole pine (*Pinus contorta* ssp. *latifolia* [Engelm.] Critchfield). The overall mean proportion of polymorphic loci was 61.19 percent, and the overall mean heterozygosity per individual was 15.81 percent. Sitka spruce was on the low side and interior Douglas-fir on the high side of overall mean genetic variation. Distribution of loci relative to frequency of heterozygotes was rather even for heterozygosities between 0.05 and 0.60; however, between 38 to 56 percent of the loci had heterozygosities lower than 0.05. More than 90 percent of the total gene diversity resided within populations. Although subpopulations were differentiated by only 2.6 to 7.9 percent, level of population subdivision was considered significant for the species tested. The overall pattern of genetic differentiation agreed with the expected on the basis of the neutral-mutation theory. Some loci, however, demonstrated conspicuous clinal variation patterns that are not readily compatible with this stochastic model.

The recent use of gel electrophoresis in isozyme studies of genic variability in natural populations of conifers (Rudin 1976) has permitted researchers to investigate many basic questions of evolutionary biology. These questions concern levels of heterozygosity within populations, distribution of genic variation within and between local populations, and relative amounts of genetic variation in central, as opposed to, marginal populations. Until recently, most investigators addressing these questions on conifers were restricted to a small sample of loci. A striking feature of the more recent and extensive isozyme surveys, however, has been the demonstration of a high degree of interlocus variation in heterozygosity within populations (O'Malley and others 1979, Yeh and El-Kassaby 1979, Yeh and Layton 1979).[3] It is imperative, therefore, that a large sample of loci be surveyed when assessing isozyme variation in conifers.

For the past 3 years, the major thrust of our research in British Columbia has concerned several conifers of commercial importance. Up to 30 loci were identified and used as genetic markers in population surveys to quantify the amount and organization of genetic variation in coastal and interior Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), Sitka spruce (*Picea sitchensis* [Bong.] Carr.), and lodgepole pine (*Pinus contorta* ssp. *latifolia* [Engelm.] Critchfield). Our research has not been restricted to the theoretical issues of evolutionary relationships between populations, but has focused on problems that complement our applied tree-breeding program. This latter aspect includes defining subpopulations, delineating seed transfer rules, and investigating associations between allozyme frequencies and quantitative traits for indirect selection.

This paper summarizes results of our study on the amount and organization of genetic variation in Douglas-fir, Sitka spruce, and lodgepole pine.

GENETIC VARIATION IN SEVERAL SPECIES OF CONIFERS

Nineteen enzymes were surveyed by one of five buffer systems (*table 1*). Data were collected in our laboratory on the basis of electrophoretic surveys of protein extracts from individual megagametophytes (*table 2*). These data show the proportion of loci polymorphic, defined as the proportion of loci in which the most common allele does not exceed a frequency of 0.99, and the proportion of loci at which an individual can be expected to be heterozygous (Nei 1973). Because the criterion defining polymorphic loci is somewhat arbitrary[3] and has a high variance as a result of the relatively small number of loci surveyed, the heterozygosity per individual is the more informative figure.

For the species shown (*table 2*), from 51 to 59 percent of the loci were segregating within a population, and the heterozygosity per individual fell in a relatively narrow range for all species, between 14.67 and 17.47 percent. The overall mean proportion of polymorphic loci was 61.19 percent and the overall mean heterozygosity per individual was 15.81 percent. Values for Sitka spruce were on the low side, and those for interior Douglas-fir were on the high side of the overall mean genetic variation. It is not incorrect, therefore, to characterize these conifers as being polymorphic for 60 percent of their genes, and individuals ithin the species as being heterozygous for about 16 rcent of their loci. It must be emphasized that these rveys were concerned only with alleles that are detected / using conventional starch gel techniques. Only a oportion—probably no more than 33 percent of all ssible mutant alleles that produce structural changes in zyme proteins—are detected in conventional electro-oretic surveys. The true level of gene diversity in these nifers, therefore, is likely to be greater than these timates suggest. Probably many isozyme differences cur that are not detected by the procedures currently ed in our laboratory (Coyne 1976). The rich gene pool in nifers is not surprising because they are exceedingly riable in morphology, both across their native range and om tree-to-tree within stands.

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[1] Presented at the Symposium on Isozymes of North American Forest Trees and Forest Insects, July 27, 1979, Berkeley, Calif.

[2] Technical Advisor in Genetics, Research Branch, British Columbia Ministry of Forests, Victoria, B.C., Canada.

[3] **Yeh, F. C., and D. M. O'Malley. Enzyme variations in natural populations of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco.) from British Columbia. I. Genetic variation patterns in coastal populations. Silvae Genetica (in press).**

This high level of gene diversity probably results from a mber of variables. Most conifer species grow in large ntinuous stands over wide geographic ranges. Divergent lection for macrogeographical adaptation (Allard and hers 1972), balancing selection for microgeographical ferentiation (Hamrick and Allard 1972, Mitton and hers 1977), combined with an open breeding system that cilitates gene flow within and between subpopulations, nd to maintain a rich gene pool. Heterosis would omote further the maintenance of genetic variation. The table exception to this pattern is red pine (*Pinus resinosa* t.) (Fowler and Morris 1977). The lack of genetic riation within this species, however, has been pothesized as being the result of a severe bottleneck, obably during the Pleistocene, when red pine was duced to a small refugial population.

Estimates of mean heterozygosity (*table 2*) are mparable to that of 10 percent obtained by outbreeding ganisms (Nei 1975) but are considerably lower than those ported previously for coastal Douglas-fir (Yang and hers 1977) and Norway spruce (Lundkvist and Rudin 77). This difference results from the bias introduced by small sample of loci analysed in the above two studies.

The standard errors of average heterozygosity empha-e the importance of examining a large number of loci (*table 2*). These standard errors are calculated from the variance among loci after the heterozygosities are averaged for populations within a species. They average about 25 percent as large as the mean heterozygosities. Such large

Table 1–*Enzymes assayed and procedures used in the survey of genic heterozygosity in some species of conifers*

Enzyme	Buffer system[1]	Loci scored		
		Douglas-fir	Sitka spruce	Lodgepole pine
Acid phosphotase (APH)	A	(*)	(*)	1
Aconitase (ACO)	A	1	1	1
Adenylate kinase (AK)	E	(*)	(*)	2
Alcohol dehydrogenase (ADH)	C	(*)	(*)	1
Aldolase (ALD)	A	1	1	(*)
Aspartate aminotransferase (AAT)	B	2	2	2
Diaphorase (DIA)	C	1	3	2
Esterase (EST)	C	1	1	(*)
Glucose-6-phosphate dehydrogenase (G6P)	A	1	1	1
Glutamate dehydrogenase (GDH)	B	1	1	1
β-Glucosidase	A	(*)	(*)	1
Isocitrate dehydrogenase (IDH)	C	1	1	1
Malate dehydrogenase (MDH)	E	4	3	4
Malic enzyme (ME)	A	2	1	2
Peptidase (PEP)	E	2	3	1
Phosphoglucose isomerase (PGI)	B	1	2	1
Phosphoglucomutase (PGM)	C	1	2	1
Superoxide dismutase (SOD)	B	1	(*)	(*)
6-phosphogluconic dehydrogenase (6PG)	C	1	2	2

[1] A = Morpholine-citrate pH 6.1; B = Tris-citrate:Li-borate pH 8.5; C = Tris-citrate pH 7.0; D = Histidine-citrate pH 7.0; E = Phosphate-citrate pH 7.0.

(*) Not assayed.

Table 2–*Survey of genic heterozygosity in some species of conifers*

Species	Populations	Loci	Proportion of loci polymorphic per population[1]	Heterozygosity per locus and standard error	Reference
Pseudotsuga menziesii (Mirb.) Franco					
coastal variety	11	21	0.6883	0.1546 ± 0.0370	Yeh and O'Malley (1979)
interior variety	11	21	.6800	.1747 ± .0422	Yeh (In preparation)[2]
Picea sitchensis (Bong.) Carr.	10	24	.5130	.1467 ± .0400	Yeh and El-Kassaby (1979)
Pinus contorta ssp. *latifolia* (Engelm.)	10	25	.5914	.1544 ± .0365	Yeh (In preparation)[3]
Critchfield	9	25	.5867	.1601 ± .0380	Yeh and Laytcn (1979)

[1] The frequency of the most common allele is ⩽0.99.

[2] Yeh, F. C. Enzyme variations in natural populations of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) from British Columbia. II. Genetic variation patterns in interior populations. Manuscript in preparation at the Research Branch, British Columbia Ministry of Forests.

[3] Yeh, F. C. Altitudinal genetic differentiation in lodgepole pine (*Pinus contorta* ssp. *latifolia* [Engelm.] Critchfield). Manuscript in preparation at the Research Branch, British Columbia Ministry of Forests.

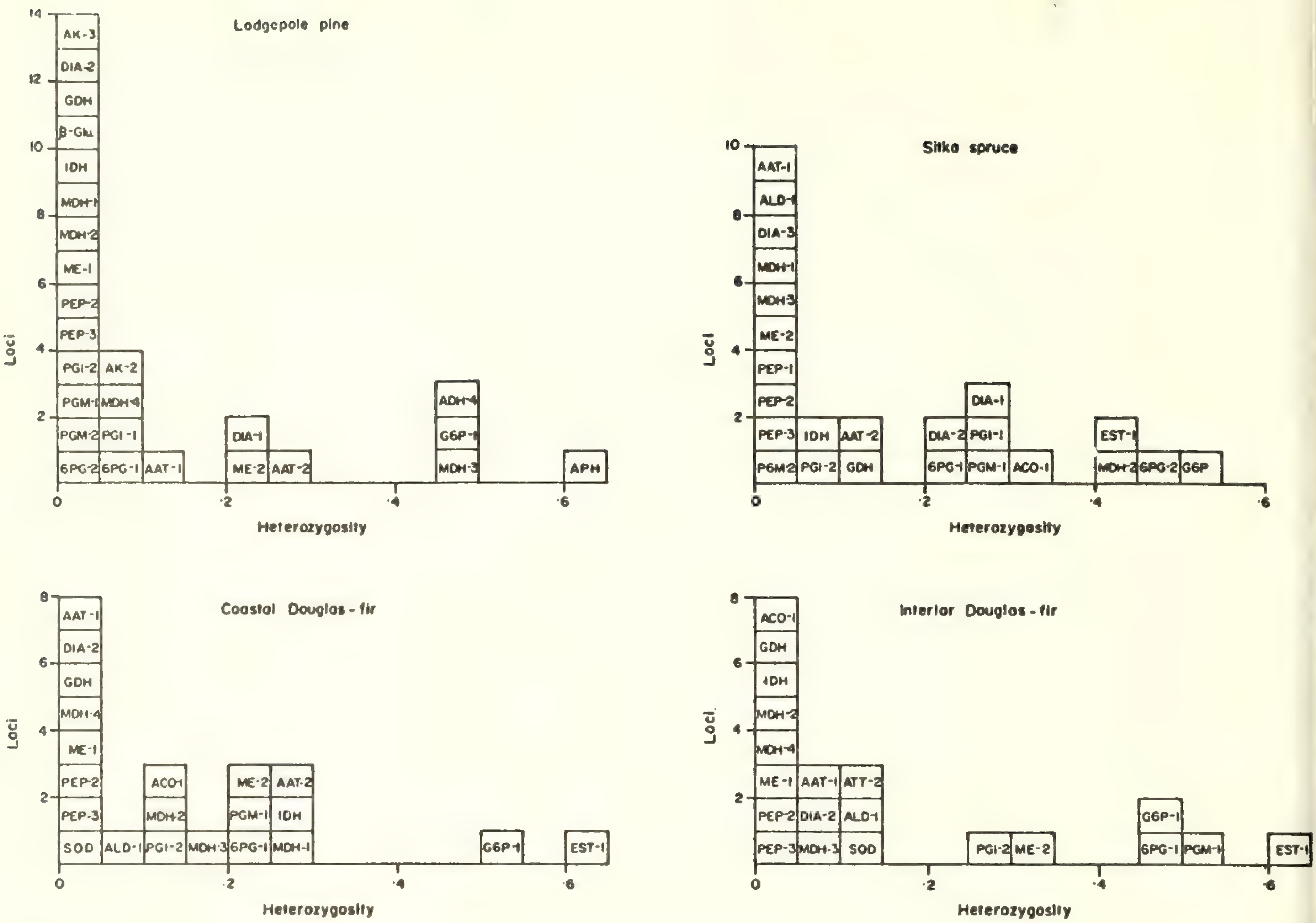

Figure 1—Distribution of heterozygosities for alleles determining electrophoretic variants in some species of conifers.

standard errors arise when loci differ markedly in their levels of variation.

Distribution of heterozygosities for alleles determining electrophoretic variants showed much interlocus variation in heterozygosity (*fig. 1*). Although no variation was apparent at some loci, at other loci more than 50 percent of the individuals were heterozygous. Distribution of the loci relative to the frequency of heterozygotes was rather even for heterozygosities between 0.05 and 0.60; however, between 38 to 56 percent of the loci analysed had heterozygosities lower than 0.05. The loci surveyed, therefore, do not seem to be equivalent in their contribution to the overall mean heterozygosity of the species. This broad range in heterozygosity, with a mode approaching zero, suggests that many isozyme loci should be surveyed to estimate reliably the amount of genetic variation in conifers. Because of such heterogeneity, interpretations on the basis of differences in detected heterozygosity between species should be considered tentative until a large number of loci are studied. Lewontin (1974) estimates that as many as 100 loci may be needed to adequately estimate heterozygosity and, at the present time, only studies of protein variation in human populations have approached this level of sampling.

ANALYSIS OF GENE DIVERSITY

Existing electrophoretic data on gene diversity was summarized in terms of its hierarchical organization in several species of conifers (*table 3*). This analysis (Nei 1973) enables genetic variation to be partitioned among different hierarchical levels of population structure—within, as opposed to between subpopulations. The technique is a modification of Wright's F-statistics (Wright 1965) expanded to multiple alleles, and is not dependent on the detection of genotypic frequencies. H_T estimates the total genetic variation sampled for all populations; it is a function of the mean allelic frequencies of the species. H_S is an estimate of the average amount of genetic variation maintained within any one subpopulation of a species. Hs can be interpreted as the proportion of loci at which an individual can be expected to be heterozygous. If all subpopulations are members of a single large panmictic unit and no gene differentiation exists among them, then all alleles will be equally distributed over the entire range and H_T will equal H_S. In nature, however, this is not true. Natural populations tend to differentiate over time into subpopulations because of the processes of mutation, selection, random drift, and restricted gene flow.

Therefore, H_S will be a subset of H_T. The extent of subdivision of a species can be described by partitioning he total gene diversity (H_T) into its components, the gene diversity within subpopulations (H_S) and between subpopulations (D_{ST}). The relative measure of genetic differentiation between subpopulations (G_{ST}) is defined by $G_{ST} = D_{ST}/H_T$ and its sampling variance [$V(G_{ST})$] can be used to study the significance of the effect of population subdivision (Chakraborty 1974).

For the species shown (*table 3*), subpopulations were differentiated by 2.6 to 7.9 percent of the electrophoretically determined variation. Nevertheless, the standard errors of G_{ST} average about 11 percent of estimates of G_{ST}. This indicates that the level of population subdivision is significant for the different species. The apportionment of otal gene diversity in these conifers is similar to that in man (Nei and Roychoudhury 1972) and in the horseshoe crab (Selander and others 1970) where more than 90 percent of the total gene diversity resides within local populations. That the majority of genic variation in conifers is maintained within populations is, perhaps, a eflection of their ecological amplitude, their breeding system, and the lack of effective barriers to gene flow between subpopulations.

MAINTENANCE OF GENETIC VARIATION

Genetic variation in natural populations detected by electrophoretic techniques is always confronted with the problem of determining the nature and relative roles of selection and neutral mutations in maintaining the observed variability. Only in a few examples have these been determined unequivocally. To encourage the possibility of making this distinction, I attempt here to nfer the mechanism responsible for the maintenance of genetic variation in those conifers surveyed in this study.

One test of the neutral-mutation theory is to compare the heoretical variance of population heterozygosity, Var(H), with the observed variance. The theoretical variance is given by Stewart (1976) as

$$\mathrm{Var}(H) = 2\theta / \{(\theta + 1)^2 (\theta + 2)(\theta + 3)\}$$

in which

$\theta = 4N\mu$

N = the effective population size

μ = the mutation rate per locus per generation

The value of θ may be estimated by $\hat{H}/(1 - \hat{H})$, in which $\hat{H}$ is the estimate of average heterozygosity, as the expectation of $\hat{H}$ is $\theta/(1 + \theta)$.

In the data for coastal Douglas-fir,[3] Sitka spruce (Yeh and El-Kassaby 1979), and lodgepole pine (Yeh and Layton 1979), the expected and observed variances of population heterozygosity agree with each other surprisingly well. This agreement suggests that the observed patterns of isozyme variation are not primarily a response to selection along macroenvironmental gradients. Certain kinds of selection and varying mutation rates per locus, of course, may produce the same effect (Li 1978). Furthermore, our sampling strategies are not sensitive to microgeographical variation. Considering that the vast majority of a species' genic variation is maintained within local populations, selection may have much significance in operating on microsite differences.

An exhaustive analysis and discussion on micro- and macro-geographical genetic variation is beyond the scope of this report. It will suffice here, however, to note that patterns of variation at many loci studied in conifers are consistent generally with the expectations of a stochastic model. Several loci demonstrate conspicuous clinal variation patterns, however, that are not readily compatible with this model. Whether these nonrandom patterns of variation are the result of drift (Karlin and Richter-Dyn 1976), or selection on the enzyme themselves, or on the coadapted complexes that they mark, is problematical.

Table 3–*Analysis of gene diversity in some species of conifers*[1]

Species	Populations	Loci	H_T	H_S	G_{ST}	Reference
Pseudotsuga menziesii (Mirb.) Franco						
coastal	11	21	0.1594	0.1546	0.0260 ± 0.0025	Yeh and O'Malley (1979)
interior	11	21	.1825	.1747	.0428 ± .0063	Yeh (In preparation)[2]
Picca sitchensis (Bong.) Carr.	10	24	.1593	.1467	.0790 ± .0112	Yeh and El-Kassaby (1979)
Pinus contorta ssp. *latifolia* (Engelm.) Critchfield	9	25	.1670	.1601	.0411 ± .0055	Yeh and Layton (1979)

[1] H_T estimates the total genetic variation sampled for all populations; H_S estimates the average amount of genetic variation maintained within any one subpopulation of a species; G_{ST} is the relative measure of genetic differentiation between subpopulations defined by $(H_T - H_S)/H_T$.

[2] Yeh, F. C. Enzyme variations in natural populations of Douglas-fir in British Columbia. II. Genetic variation patterns in interior populations. Manuscript in preparation at the Research Branch, British Columbia Ministry of Forests.

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An Analysis of Genetic Architecture in Populations of Ponderosa Pine[1]

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Abstract: Patterns of genetic variation were studied in three populations of ponderosa pine in Colorado by using electrophoretically variable protein loci. Significant genetic differences were found between separate clusters of trees and between age classes within populations. In addition, data indicate that differential cone production and differential animal damage have genetic components. These results suggest that many diverse phenomena can affect allele frequencies within populations and may contribute to the high levels of genetic variability detected within populations of this species.

Assessments of genetic variation in forest trees have been aided greatly by the use of electrophoretic ana- yses of protein polymorphisms. Many such studies ave concentrated on the distribution of this variation over broad geographic range (for example, Guries and Ledig 981, Lundqvist and Rudin 1977, and Yeh 1981). Results ocument that substantial variation exists in trees and that his variation is distributed in patterns determined rimarily by the heterogeneity of the physical environ- nents. These findings agree with data on patterns of eographic variation collected by earlier forest geneticists anglet 1971, Libby and others 1969). Small-scale atterns—over a distance of 1 km or less—are less well ocumented but increasing evidence suggests that ifferentiation can occur in forest trees over distances as nall as a few hundred meters (Barber 1965, Benson and thers 1967, Herman and Lavender 1967, Mitton and thers 1977, Grant and Mitton 1977). Again, this ifferentiation is associated with significant environmental eterogeneity produced by elevation, slope, or exposure.

The results mentioned above describe the organization genetic variation between populations but say little bout variation within populations. Within-population riation is particularly worthy of interest at this time, nce several studies have suggested that in some forest ees, including ponderosa pine, such variation is gnificantly greater than variation between populations ines and Mitchell 1966, Madsen and Blake 1977, 'Malley and others 1979).

Many variables can affect the patterning of genetic riation within populations, including differential edation by animals and restricted pollen and seed spersal. Also, trees are long-lived and environmental nditions change with time. As a result, different notypes may reproduce in different years and natural selection operating on seedlings may involve different forces in different years. Consequently, generations of different genetic constitutions may exist within multiaged stands.

This paper reports a study dealing specifically with patterns of intrapopulation variation. In 1976, we began studying populations that occupy relatively small areas, from 2 to 5 hectares, within which the heterogeneity of the physical environment is limited. We investigated three populations of ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) in Colorado for (a) spatial distribution of genotypes within a given population and (b) genetic differences between age groups within a given population. We also investigated whether (c) genetic differences exist between trees that reproduce heavily and those that do not and, finally, (d) whether animal damage in the form of deer browsing or woolly aphid infestation is related to genetic constitution of the trees.

MATERIALS AND METHODS

All populations in our study grow in the Front Range of the Rocky Mountains, near Boulder, Colorado. None of them have been heavily disturbed by human activities, such as heavy logging or tree planting nearby. One population (Boulder Canyon) has been analyzed in detail; comparative data for some of the phenomena being studied are available from the Glacier Lake and Shanahan Mesa populations.

Genetic Methods

All genetic analyses are made on the basis of enzyme polymorphisms detectable in extracts of mature needle tissues. Because we are studying patterns of variation, only polymorphic loci are investigated.

The enzyme polymorphisms being studied include one peroxidase (PER-2, 3 alleles), one phosphohexose isomerase (PHI, 3 alleles), two phosphoglucomutase loci (PGM-1, 2 alleles and PGM-2, 3 alleles), one glutamate dehydrogenase (GDH, 2 alleles), one colorimetric esterase (C.E., 3 alleles), and one fluorescent esterase (F.E., 3 alleles). Patterns of Mendelian inheritance are reported elsewhere (Mitton and others 1977, 1979).

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[1] Presented at the symposium on Isozymes of North American Forest ees and Forest Insects, July 27, 1979, Berkeley, Calif.

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[3] Graduate student, Department of Environmental, Population, and ganismic Biology, University of Colorado, Boulder, Colo.

Methods of preparation of needle extracts, resolution and staining are reported in the following publications: Mitton and others (1977) for PER-2; Mitton and others (1979) for all other loci.

Heterogeneities of allele frequencies were tested with the chi-square test of Workman and Niswander (1970).

Boulder Canyon Population

This population, within a pure ponderosa pine stand on the south-facing slope of Boulder Canyon at 1738 m, consists of all individuals—with the exceptions of a few seedlings—within an area of about 2 hectares (*fig. 1*). The population is located in the ponderosa pine belt typical of the lower elevations of the Colorado Front Range.

We numbered and mapped all pines in the population. We recorded age, diameter, pollen and cone output, presence or absence of infestations by woolly aphids (*Pineus coloradensis* Hopk.), browsing by deer (*Odocoileus demionus* Raf.) and the genetic constitution at all seven polymorphic protein loci.[4]

We compared the genetic constitutions of the six clusters of trees in the population. In 1977, we compared trees producing at least some pollen with those that did not, and we also counted all mature female cones. We compared prolific cone producers with poor cone producers, correcting for the effects of age and size on cone production (Linhart and others 1979a).

We analyzed browsing by mule deer, and we compared the genetic constitutions of heavily browsed trees to those of lightly or unbrowsed trees. We also compared trees that had woolly aphids on their foliage in 1979 with those that did not.

Glacier Lake Population

This population is also on a south-facing slope, at 2590 m. Here the forest is composed primarily of ponderosa pine, with Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), limber pine (*Pinus flexilis* James), and juniper (*Juniperus scopulorum* Sarg.) intermixed. We tagged and mapped approximately one-third of the ponderosa pines within a 4-ha area. In contrast to the Boulder Canyon population, some disturbance occurred here in about 1900 when scattered logging was done in the area. Furthermore, during our study, an outbreak of bark beetles (*Dendroctonus ponderosae* Hopk.) killed more than one-third of the trees. As a result, the spatial structure of this population is not as stable as it is in the Boulder Canyon population. In this population we investigated primarily the spatial distribution of genetic variation at three loci: PER, C.E. and R.E.

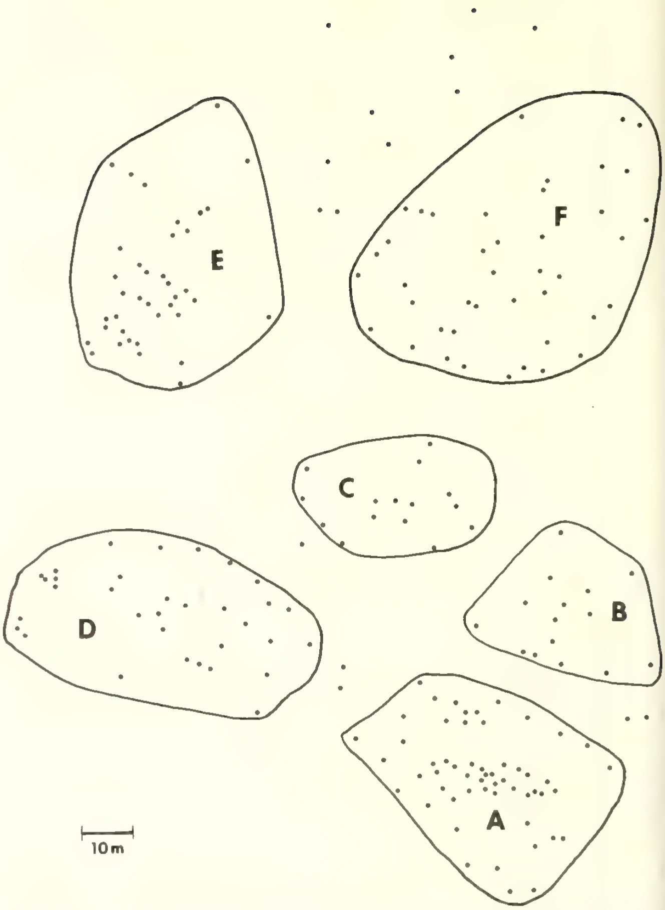

Figure 1—Approximate distribution of trees in a stand of ponderosa pine in Boulder Canyon, Colorado. Six clusters have been defined and are labeled A through E. In the text, these are called the Boulder Canyon Population. Age structures of all clusters are also shown.

Shanahan Mesa Population

This population, at an elevation of 1700 to 2000 m, is on an east-facing mesa at the base of the Front Range. The mesa was grass-covered until about 120 years ago when ponderosa pine started to colonize the area from seed dispersed from stands growing on the steep slopes above the mesa. In one area, a second generation of saplings has become established under the closed canopy of the mature trees (Beckman 1977).

We compared variation at the PER locus in the original colonists, which grew up in the open grassland, with variation of their offspring, which grew up under their canopy.

RESULTS AND DISCUSSION

Spatial Clustering and Genetic Differentiation

Both the Boulder Canyon and the Glacier Lake populations have clusters of trees that are easily identified.

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[4] Linhart, Y.B., J.B. Mitton, and K.B. Sturgeon. Some genetic features of clustering in a ponderosa pine population. (Manuscript in preparation.)

pen spaces are found between clusters. In each opulation, some trees, located either between clusters or the edge of the mapped area, are not clearly assignable to given cluster and, therefore, are omitted from the mparisons. In both populations we found significant fferences in allele frequencies among the various clusters *able 1*). Genetic heterogeneity is particularly striking in e Boulder Canyon population where nearby clusters can ry by as much as 20 percent at GDH, 21 percent at C.E., 2 percent at PER-2, and 29 percent at F.E. We found little trapopulation variation at the other three loci tested—GM-1, PGM-2, and PHI have their most common alleles frequencies of 88 to 100 percent in all clusters. Similar sults are found in the Glacier Lake population (*table 1*).

Similar genetic differentiation between carefully map-ed, nearby clusters of plants has also been documented for *inanthus parryae* (Gray) Greene (Epling and Dobzhan-y 1942), *Liatris* (Schaal 1975), *Pinus sylvestris* L. (Rudin d others 1977), and *Picea abies* (L.) Karst. (Tigerstedt 73). Tigerstedt believed that evidence for such terogeneity was lacking within the populations he udied; however, an analysis of his figure 4 shows that, if e divides that population into two segments by an E-W e running through the center of the mapped area, the fast lele at the LAP locus is at a frequency of 0.67 in one area mposed of 24 trees, and at a frequency of 0.39 in the her area composed of 23 trees. This difference is gnificant ($X^2 = 16.49$, 1 d.f., $P < 0.005$). Some evidence so exists for clustering and genetic heterogeneity in local pulations of other trees. These include *Pseudotsuga enziesii* (Mirb.) Franco (Rehfeldt 1978, Shaw and Allard 81), *Cupressus macrocarpa* Hartw. (Kafton 1977), *orea leprosula* Miq. (Dipterocarpaceae), and *Xero-ermum intermedium* Radlk. (Sapindaceae) (Gan and hers 1977) and *Fagus* (Stern and Roche 1974). No evidence was found, however, for such clustering in populations of *Pinus rigida* Mill. (Guries and Ledig 1977) or *Pinus taeda* L.[5]

The genetic differentiation observed between nearby clusters probably results in part from the genetic relatedness of trees within a cluster. Such relatedness may occur when most seeds from a given parent tree are dispersed within a small area. Even if the pollen that fertilized the parent tree is a completely random sample of the pollen available in the stand, the group of trees arising from the seed rain of a single parent is a group of half-sibs. Also, those wind-dispersed seeds that are least likely to be transported any distance are those produced in the lower portion of a crown; those seeds also happen to be the ones that are most likely to have been produced by self-pollination (Fowler 1965). This fact may contribute to the genetic relatedness among individuals within a group.

Inbreeding, in the absence of selection, would be expected to produce deficiencies of heterozygotes relative to Hardy-Weinberg expectations. The distribution of genotype frequencies within given clusters compared with frequencies expected under Hardy-Weinberg equilibrium showed few significant departures from expectations. In the Glacier Lake population, no departures were observed. In Boulder Canyon, at the PER-2 locus, group B had 13 heterozygotes in a total of 15 trees ($X^2 = 7.13$, 2 d.f., $P < 0.05$), and group D had 24 heterozygotes in a total of 33 trees ($X^2 = 13.75$, 2 d.f., $P < 0.005$). Both of these departures result from excesses of heterozygotes. There are only two significant deviations in the 24 tests (6 clusters x 4 highly variable loci) that we performed, and these observations may be fortuitous. They may also reflect

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[5] Personal communications from F. T. Ledig, and from M. Thompson Conkle, geneticists, Forest Service, U.S. Dep. Agric., July 26, 1979.

Table 1—*Allele frequencies ± standard errors for the most common allele at several protein loci among clusters within two populations of ponderosa pine*

Locus (allele)	Cluster A	B	C	D	E	F	X^2	P
				Boulder Canyon Population				
PER-2 (2)	0.787 ± 0.04	0.567 ± 0.08	0.750 ± 0.08	0.712 ± 0.06	0.737 ± 0.05	0.721 ± 0.05	11.39 (10 d.f.)	<0.20
GLU (1)	.723 ± .04	.633 ± .08	.532 ± .09	.697 ± .06	.711 ± .05	.733 ± .05	5.34 (5 d.f.)	< .40
F.E. (2)	.630 ± .05	.667 ± .08	.750 ± .08	.742 ± .05	.461 ± .06	.547 ± .05	21.72 (10 d.f.)	< .025
C.E. (1)	.722 ± .04	.767 ± .08	.563 ± .09	.773 ± .05	.697 ± .05	.767 ± .05	25.01 (10 d.f.)	< .01
Total trees	54	15	16	33	38	43		
				Glacier Lake Population				
PER-2 (2)	0.709 ± 0.05	0.783 ± 0.06	0.725 ± 0.06	0.833 ± 0.07	0.727 ± 0.05	0.833 ± 0.07	1.28 (4 d.f.)	<0.90
F.E. (2)	.535 ± .05	.522 ± .08	.500 ± .08	.714 ± .07	.583 ± .06	.667 ± .08	17.30 (8 d.f.)	< .05
C.E. (1)	.628 ± .05	.696 ± .06	.550 ± .08	.785 ± .07	.693 ± .06	.667 ± .08	12.42 (8 d.f.)	< .20
Total trees[1]	43	23	20	14 to 15	31 to 44	18		

[1] For clusters D and E, this number is variable because some trees died before their genotype at a given locus could be ascertained.

different selection pressures: other populations of ponderosa pine at comparable elevations also show excesses of heterozygotes at the PER-2 locus (Mitton and others 1977).

The extent of differentiation between clusters reported here is high: there may be greater genetic differences between some clusters *within* these pine populations than are found between populations separated by many kilometers in other species. One way to compare levels of differentiation is by estimating genetic distance, D (Nei 1972). Such comparisons must be done with caution because values of D are affected by the relative proportion of monomorphic loci used in the calculations. Because we used only polymorphic loci in our calculations of D, our results can be compared to those of Lundqvist and Rudin (1977) who used four polymorphic loci in studying *Picea abies* (L.) Karst. populations throughout Sweden, and those of Levin (1977) who used seven polymorphic loci in studies of *Phlox drummondii* Hook. subspecies throughout Texas. Lundqvist and Rudin reported D values of 0.002 to 0.039 between native populations. Levin reported a mean distance, $\bar{D}$ of 0.02 between all subspecies.

The Boulder Canyon clusters had a $\bar{D}$ of 0.015, with a range of 0.004 to 0.035; Glacier Lake had a $\bar{D}$ of 0.022, with a range of 0.006 to 0.055.

Genetic Differentiation Between Age Classes

The Shanahan Mesa population provides detailed evidence of how selection pressures within a population can change during a few years as a result of changes in the environment. Such changes in selection pressures produced significant genetic differentiation between age classes. The analysis was with the PER-2 locus, which has three alleles. Other studies have shown that allele 2 is found most frequently in the moister, cooler conditions prevalent at higher elevations (above 2400 m) and north-facing slopes. Alleles 1 and 3 are found most frequently in the warmer, more xeric conditions prevalent at lower elevations (below 1800 m) and on south-facing slopes (Mitton and others 1977). Also, 23 heterozygotes occur in frequencies significantly higher than those predicted by Hardy-Weinberg expectations in all populations growing in relatively warm, xeric conditions. Beckman (1977) studied the kinetics of the allozymes and found that the biochemical evidence was consistent with results from field observations: a 22 genotype produces an enzyme that functions best at cool temperatures; 13 and 33 genotypes produce enzymes that function best at warm temperatures; and a 23 genotype functions well over a broader range of temperatures than do the other genotypes.

At Shanahan Mesa, two well-defined size and age classes exist. In certain areas dominant trees that form the canopy are more than 40 years old, have colonized the open grasslands, and have had to survive in the relatively xeric conditions of these grasslands. Beneath them grow their offspring—trees that developed in the much moister, cooler conditions provided by a closed canopy. Under this canopy, snow accumulates and can remain for several weeks. In contrast, the snowfalls on the adjacent prairie are blown away by frequent winds or melted by the sun within days. Significant differences exist between these two groups at the PER-2 locus. The old colonizers have significantly higher frequencies of alleles 1 and 3 (0.200) than do the younger trees (0.060); this difference is significant ($X^2 = 6.40$, $P < 0.025$). In addition, there are significant excesses of heterozygotes in the old colonizers, whereas genotypic frequencies in the young trees conform to Hardy-Weinberg expectations (Beckman 1977). The associations between allele 2 and cool conditions, and alleles 2 and 3 and hot, xeric conditions are so consistent, that we believe the results at Shanahan Mesa truly reflect genetic differentiation in response to environmental conditions that changed during the span of 120 years. In the Boulder Canyon population, the genetic make-up of the major age classes was compared at seven loci. There were no striking genetic differences between them.

Genetic Aspects of Differential Reproduction

Natural selection results in part from differential reproduction of genotypes (Darwin 1859), but only a few published reports document differential reproduction of genotypes in natural populations (Eanes and others 1977, Clegg and others 1978). We wish to know if reproduction in individual trees is related to their allozyme genotypes. Because it is difficult to estimate accurately total pollen production for a population, we compared the genetic constitution of trees that produced pollen with those that did not. Three loci—PER-2, F.E. and C.E.—were analyzed in the Boulder Canyon and Glacier Lake populations, and PER-2 only was analyzed in a third population near Glacier Lake. Results were the same for all comparisons: no genetic differences were detected between trees producing pollen and those that did not in 1977 (Linhart and others 1979b).

Female cone production can be measured accurately in the trees we study because the stands are open, and the trees are no taller than 15 m. Cone production is affected by both tree size and age in conifers (Schubert 1974, Dorman 1976). To describe cone production as a function of age and size, we performed a multiple regression analysis of cone production, using age and diameter of trees as independent variables. To get an accurate estimate of differential cone production in the Boulder Canyon population, we compared the trees whose cone production deviated most strikingly from that expected for their diameter and age. We compared the 50 trees that most exceeded their expected cone production to the 50 trees that were farthest below expectations. Results show that in 1977, a mast year, significant differences existed at several loci between high cone producers and low cone producers (*table 2*).

That differential cone production in trees has a significant genetic component is not unexpected. Much ricultural research on selection for higher yields in plants d animals has underscored the importance of this genetic mponent (Allard 1960). Recent studies using allozyme arkers have usually (Schall and Levin 1976, Eanes and hers 1977, Clegg and others 1978), though not always hristiansen and Frydenberg 1976), found genetic fferences between reproducing and nonreproducing dividuals. However, this genetic component needs more cognition in forestry research: a recent exhaustive view of research on reproduction in southern pines orman 1976) shows that little of that research has cused on the genetic and evolutionary implications of ferential reproduction.

nimal Damage and Its Genetic nplications

Patterns of deer browsing in 1977 and the presence of olly aphids in 1979—the only years for which we have alyzed data so far—have distributions that are affected the genetic constitutions of trees in the Boulder Canyon pulation. A comparison of the genetic constitution of avily browsed trees with that of unbrowsed or lightly owsed trees at three loci showed that, although at PER-2 d F.E. we found no statistically significant differences, at E. the frequencies of alleles 1 and 2 combined were 0.791 the heavily browsed and 0.672 in the lightly browsed es ($X^2 = 4.635$, $P < 0.05$). In addition, a preference by er for particular genotypes has been shown in *eudotsuga menziesii* (Mirb.) Franco (Radwan 1972).

Woolly aphids are common on ponderosa pine in the ntral Rocky Mountains. We scored all trees in the Boulder Canyon population for presence or absence of woolly aphids by sampling 40 branches per tree. Trees with aphids (N = 51) were compared with trees without aphids (N = 166) in the frequencies of the most common allele and of all other alleles pooled together. Significant differences were found at the F.E. locus. The frequencies of allele 2 was 0.500 in trees with aphids, and 0.651 in noninfested trees ($X^2 = 6.82$, $P < 0.01$). These data suggest that patterns of animal attacks on trees are not random. Similar results have been obtained in ponderosa pine by Edmunds and Alstadt (1978) in a study of the black pine leaf scale, *Nuculapsis californica*, and by Sturgeon (1979) in a study of the bark beetle, *Dendroctonus brevicomis*.

able 2–*Comparisons between individuals with low and high relative one productions in a population of ponderosa pine, at the Boulder anyon population*

Locus	Allele	Cone production		Chi square	Significance
		Low F ± S.E.	High F ± S.E.		
ER	1	0.07 ± 0.026	0.01 ± 0.010	5.5	P < 0.07
	2	.71 ± .045	.70 ± .046		
	3	.22 ± .041	.29 ± .045		
LU	1	.66 ± .047	.74 ± .044	1.6	P < .50
	2	.34 ± .047	.26 ± .044		
.E.	1	.20 ± .040	.31 ± .046	6.6	P < .05
	2	.74 ± .044	.57 ± .050		
	3	.06 ± .024	.12 ± .035		
HI	1	.01 ± .010	.01 ± .010	1.4	P < .50
	2	.98 ± .014	.99 ± .010		
	3	.01 ± .010	.00		
.E.	1	.67 ± .047	.82 ± .038	5.9	P < .05
	2	.05 ± .044	.03 ± .017		
	3	.28 ± .045	.15 ± .035		
GM-1	1	.03 ± .017	.08 ± .027	2.5	P < .50
	2	.97 ± .017	.92 ± .027		
GM-2	1	.09 ± .029	.06 ± .024	2.2	P < .50
	2	.90 ± .030	.94 ± .024		
	3	.01 ± .010	.00		

Synthesis

The genetic clustering reported in the species cited in this report presents a different picture from the one observed in some other conifers studied to date. For example, no subdivision has been detected in *Pinus rigida* Mill. (Guries and Ledig 1977) or *Pinus taeda* L.[5] Rudin and others (1977) studying *Pinus sylvestris* L. and Tigerstedt (1973) studying *Picea abies* (L.) Karst. show that in these species the subdivision is not very pronounced. These differences may result, in part, from study techniques: our study at Boulder Canyon involves mapping of all individuals established within a given area, with a sample size of more than 200 individuals; the studies cited earlier typically involved selected individuals and sample sizes of 60 to 70 trees. More importantly, the differences probably reflect real differences in biological features of the species concerned. Ponderosa pine in the Rocky Mountains often grows in all-aged stands which are composed of patches of relatively uniform size and age (Schubert 1974). In species where such mosaics do not occur, and where stands are primarily single-aged and single-sized, less opportunity for such differentiation exists. This may be particularly true in species such as *Pinus rigida* Mill. that depend on fire for their establishment, so that extensive stands get started under similar conditions.

Because heterogeneity of the physical environment is limited within a site, causes of the heterogeneity must be sought elsewhere. We believe that clusters are probably composed of genetically related individuals, given the short dispersal distances of both tree seeds (Levin and Kerster 1974) and viable pollen (Coles and Fowler 1976, Muller 1977). Differentiation among clusters may also occur if different clusters, which have different age structures (*fig. 1*), come from genetically-different parents, are exposed to different selective pressures in their early years, or both. Comparisons between major age classes in ponderosa pine (Beckman 1977) have shown major age-associated genetic differences within some populations.

Animal predation may also contribute to the genetic structure of the Boulder Canyon population. Both deer and woolly aphids show preferences for some phenotypes, and it is likely that other animals with more destructive habits could practice similar discrimination.

The extent of differentiation in allele frequencies observed between clusters within the Boulder Canyon ($\bar{D}$ =0.015) and Glacier Lake populations ($\bar{D}$ = 0.022) are similar in magnitude to the differentiation between the Boulder Canyon and Glacier Lake populations ($\bar{D}$=0.030). These populations are separated by more than 1000 m in elevation and several kilometers in their linear distance. This suggests that a substantial proportion of total genetic variation can be found within populations of ponderosa pine and supports the findings of Madsen and Blake (1977) and O'Malley and others (1979). Similar results for other conifers have been obtained by Yeh (1981), Lines and Mitchell (1966), and Fins (1979). However, this observation cannot be applicable to all classes of genetic variation, otherwise we would not have witnessed the repeated disasters produced by planting seeds of far-away sources in a given area; nevertheless, it probably applies to at least some of the variability that forest geneticists are intent upon capturing.

CONCLUSIONS

The populations of ponderosa pine we have studied show a great deal of intra-population differentiation which is not obviously associated with heterogenity of the physical environment. Similar results in other herbaceous and woody species suggest that such differentiation is a common feature of the genetic structure of plant populations.

The highly localized heterogeneity we have demonstrated, along with the genetic differences observed between heavy and light cone bearers have practical implications. Whenever seed collections or regeneration after logging depend on a few trees with large numbers of cones, the genetic base of the following generations may be severely restricted. Genetic analyses, provenance studies, and seed orchards cannot produce accurate pictures of total genetic variation if they depend only on progenies from trees producing many seeds in a given year.

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Applying Isozyme Analyses in Tree-Breeding Programs[1]

W. T. Adams[2]

Abstract: Four examples illustrate the potential for practical use of isozyme analyses in applied breeding programs. These include identifying parent trees and clones, seed sources, and parentage of controlled crosses, and evaluating the effectiveness of different procedures involving open-pollination to produce seed of specific crosses. The improved ability to assess the true identity of parents, seed stocks, and controlled crosses justifies the added expense resulting from the use of isozyme analyses in applied tree-breeding programs.

Some papers in this symposium, as well as others previously published (Bergmann 1978, Guries and Ledig 1977, Lundkvist and Rudin 1977, Mitton and others 1977, Muller 1977, Rudin and others 1974), demonstrate the use of isozymes in studying genetic structure and variation patterns in populations of forest trees. Recently, isozyme investigations also have been started in seed orchards[3] (Rudin and Lindgren 1977). Information from studies in both natural and seed orchard populations no doubt will help to increase the efficiency of future tree-improvement programs.

In addition to their research value in forest genetics, isozymes have more immediate application as genetic markers in tree-breeding programs. By providing examples primarily from my own work, I illustrate several possible applications. These examples demonstrate that isozyme analyses can be used by tree breeders to determine and maintain the identity of individuals, crosses, and breeding populations with greater accuracy than was possible previously.

IDENTIFYING PARENT TREES AND CLONES

If isozymes are to be effective genetic markers in breeding programs (Rudin and Lindgren 1977), isozyme variation among parent trees or orchard clones must be large. This is expected in most forest tree species because an effort is usually made to incorporate a broad base of genotypes in breeding populations. The large isozyme variation found among clones in one pitch pine (*Pinus rigida* Mill.) breeding orchard and three loblolly pine (*Pinus taeda* L.) seed orchards[3] (Hunter 1977) supports this expectation (*table 1*). As many as nine alleles were present at any one isozyme locus, and the average percentage of heterozygous loci per clone ranged from 15 to 33 percent.

For clonal identification it is preferable to have many alleles per locus, each of about equal frequency. However, although isozyme loci in these four orchards ***(table 1)*** averaged about three alleles, one allele was usually in high frequency. Isozyme variation among these clones, therefore, was far from "ideal." Nevertheless, enough variation among clones existed so that most could be individually identified by using the sampled isozymes as genetic markers. On the basis of the 11 polymorphic loci scored in each clone, 28 unique genotypes were recognized among the 32 clones in the pitch pine orchard; similarly, 22 twelve-locus genotypes and 25 eleven-locus genotypes were recognized, respectively, among the 23 and 27 clones in the two South Carolina loblolly orchards. All 27 clones in the North Carolina loblolly orchard could be uniquely identified on the basis of their twelve-locus genotypes. Complete resolution of clones in the first three orchards could be achieved if additional loci were evaluated. These results indicate that isozyme gene markers can be useful for maintaining the identity of ortets and their ramets in a breeding program.

Hunter (1977), for example, has used isozymes to detect labeling errors in seed orchard trees. Six of the 22 clones with more than one ramet in the North Carolina loblolly orchard had at least one mislabeled ramet, discovered because the genotypes of the mislabeled ramets differed from those of the other ramets representing a clone.

The genotype of each orchard clone was determined from seed samples on the basis of the composition of allozymes (allelic isozymes) observed in megagametophytes. When this method is used, a genotype will be incorrectly identified only if all megagametophytes sampled from a heterozygote carry the same allozyme allele; with N megagametophytes, this probability is $(1/2)^{N-1}$ for a single locus. For a sample of only 10 seeds, therefore, the probability of incorrectly identifying a clone's genotype at any one locus is less than 0.2 percent. Assuming all loci are independent, the probability of error in identifying a 12-locus genotype is less than 2.5 percent.

In general, extracting enzymes from seed tissues is easier than from vegetative tissues (for example, needles, buds, or bark) of seedlings or older trees. However, analyzing

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[1] Presented at the Symposium on Isozymes of North American Forest Trees and Forest Insects, July 27, 1979, Berkeley, Calif. (Paper FRL 1389, Forest Research Laboratory, Oregon State University, Corvallis, Oreg.)

[2] Assistant Professor of Forest Genetics, Oregon State University, Corvallis, Oreg.

[3] Adams, W.T., and R.J. Joly. Allozyme studies in loblolly pine seed orchards: clonal variation and frequency of progeny due to self-fertilization. (In press.)

Table 1 – *Variation at isozyme loci polymorphic among clones in one pitch pine breeding orchard and three loblolly pine seed orchards*

Orchard[1]	Number		Alleles per locus		Most frequent allele at each locus		Heterozygous loci per clone		
	Clones	Loci	Most	Mean	Range	Mean	Range	Mean	Mean
								Number	*Percent*
Pitch pine	32	11	6	2.9	0.98 to 0.70	0.91	0 to 4	1.7	15
Loblolly pine[2] South Carolina-LSG	23	12	6	3.0	.98 to .46	.82	1 to 5	3.0	25
Loblolly pine[2] South Carolina-HSG	27	11	5	3.0	.98 to .44	.81	0 to 6	2.9	26
Loblolly pine[3] North Carolina	27	12	9	3.3	.96 to .26	.73	1 to 8	4.0	33

[1] The two South Carolina orchards are located at the same site. The low specific gravity (LSG) orchard consists of clones selected for wood of low specific gravity; the high specific gravity (HSG) orchard consists of clones selected for wood of high specific gravity.

[2] Data from Adams and Joly. (In press.)

[3] Data from Hunter (1977).

ozymes from vegetative tissues is necessary if genotypes juvenile and nonflowering mature individuals are to be entified. A set of isozyme loci expressing clearly in both ed and vegetative tissues would be of most benefit; veral examples of such loci have been reported (Bartels 71, Lundkvist 1975, Mitton and others 1977, Rudin 75).

EED CERTIFICATION

Interest in seed certification will intensify as demand for netically improved seed increases (Rudolph 1974). Be- use considerable isozyme variation has been observed nong orchard clones, the seed of individual clones or that om specific crosses can be distinguished from the seed of ost other clones or crosses. Isozymes can be used, erefore, to certify the identity of specific seed lots.

The expected frequencies of isozymes in the seed of the o South Carolina loblolly pine orchards were deter- ned by weighting each clonal genotype according to the mber of its ramets and assuming random mating (*table* [3] Genetic makeup of seed lots from these orchards was pected to be similar because the clones came from parent es in the same breeding zone and, except for wood nsity, were selected for the same qualities. This was nerally borne out—at most loci, the most frequent allele one orchard was also the most frequent in the other. fferences between orchards were also observed, how- er; some alleles had dissimilar frequencies, and some curred in one orchard but not in the other. Therefore, e could readily determine from which orchard a parti- lar seed lot was derived.

In several species, evidence is accumulating to indicate at variation in isozyme frequencies between provenances n be expected (Bergmann 1978, Lundkvist and Rudin 77, Mitton and others 1977, Rudin and others 1974). us, even greater differences in isozymes may occur ong seed lots from orchards composed of clones from rious geographical areas. Similarly, isozymes could tify the geographical origin of seed collected from natural stands (Bergmann 1972). Changes in isozyme frequency may be strongly correlated with changes in environment (Bergmann 1978, Grant and Mitton 1977, Mitton and others 1977), in which case isozymes can be helpful in defining breeding and seed zones (Feret and Bergmann 1976).

Table 2 – *Expected allelic frequencies in the seed crops of two South Carolina loblolly pine seed orchards*

Locus	Allele[2]	Orchard[1]		Locus	Allele	Orchard	
		LSG	HSG			LSG	HSG
PGI1	1	0.015	0.015	LAP2	1	0.417	0.503
	2	.985	.985		2	.583	.450
					3	–	.047
GOT1	1	.156	.007	PGI2	1	.047	–
	1L	[3]	.025		2	.822	.930
	2	.184	.362		3	.108	.057
	3	.660	.606		4	.023	.013
AP2	1	.015	.052	GOT2	1	.168	.098
	2	.889	.938		2	.007	–
	3	.096	.010		3	.829	.902
MDH2	1	.905	.993	6PGD	1	.025	–
	2	.095	.007		2	.397	.407
					3	.053	.015
LAP1	1	.065	–		4	.015	.085
	2	.836	.862		5	.503	.481
	3	.048	.045		5L	.007	–
	N	.051	.093		6	–	.012
GDH	1	–	.038	PGM1	1	.944	.978
	2	.939	.787		2	.056	.022
	3	.013	–				
	4	–	.010	PGM2	1	.028	–
	5	.048	.165		2	.972	1.00

[1] LSG is low specific gravity; HSG is high specific gravity. (From Adams and Joly. In press.)

[2] Alleles are numbered in ascending order from the fastest to the slowest migrating isozymes. N is a null allele; L is an allele coding a very lightly staining band.

[3] A dash (–) means no allele present.

DETERMINING VALIDITY OF CONTROLLED CROSSES

Tree-breeding programs usually require many controlled crosses, which generally are assumed to have been made without error. This assumption, however, has not been tested because no accurate method has been available. Using isozyme markers to test the validity of controlled crosses is relatively simple (if sizable isozyme variability exists among clones or parent trees): first, parental isozyme genotypes are determined, and second, their progeny are analyzed to see whether their isozyme makeup is as expected.

To demonstrate this application, we conducted the following study. Seeds were supplied from 30 two-parent loblolly pine crosses made by three different organizations (designated A, B, C) in the North Carolina State-Industry Cooperative Tree Improvement Program (*table 3*). Additional seed lots from all the clones involved as male parents and from clones of the female parents used in one-half of the 30 crosses also were obtained. Megagametophytes of at least 10 seeds from each parental seed lot were analyzed and the isozyme genotypes of the clones inferred at six loci. Embryo and megagametophyte tissues from 20 to 30 seeds of each of the 30 controlled crosses were then assayed at the same six loci. By analyzing both the haploid and diploid seed tissues, it was possible to determine the allelic composition of the ovule and pollen gametes forming the embryo. Because the allelic composition of the ovule is the same as that in the megagametophyte, the remaining allele (after accounting for the allele contributed by the ovule) must be from the pollen gamete. The pollen pools (that is, pollen gametes effective in fertilizing viable seeds) of the crosses, therefore, can be compared with those expected on the basis of each pollen parent's isozyme genotype; similar comparisons can be made for the ovule pools of the 15 crosses for which independent information on the genotypes of the female parents is available.

Evidence of error in female identity was found in only one (cross 18 X 19) of the 30 crosses. Seed from clone 18 had apparently been mixed with seed from one or more other clones, because five of the 20 seeds sampled contained alleles in megagametophytes that could not have come from clone 18. At least some of the contaminated seed could have come from clone 19; this clone has alleles at two loci not found in any of the other sampled clones, and both of these alleles were found in the contaminated seed. The allelic composition of megagametophytes was as expected in the remaining 14 crosses for which the isozyme genotypes of the maternal parents were known, and no more than two alleles per locus were observed among the megagametophytes of the other crosses sampled.

Pollen contamination seemed to be a real problem in organization C (*table 3*). Although the allelic compositions of the pollen pools were as expected in all but one of the 20 crosses made by organizations A and B, 8 out of 10 crosses for organization C contained alleles that could not have come from the supposed pollen parent. Apparently, procedural problems in pollen handling, bagging, or making the crosses resulted in considerable pollen contamination.

Caution is needed in comparing the validity of crosses made by different organizations when using the technique of isozyme markers. The ability to detect errors is somewhat dependent upon parents carrying alleles at one or more marker loci that are relatively infrequent among other sources of pollen. If the variation among clones is generally large, however, the results from different organizations should be roughly comparable. The extent of contamination is underestimated with this technique because contaminants having the same allelic compositions as those expected would remain undetected. Nevertheless, isozyme gene markers will probably uncover most errors in seed-handling and control-crossing procedures.

Table 3—*Number of detected pollen contaminants (d.c.)*[1] *observed in the pollen pools of seeds from 10 controlled two-parent crosses of loblolly pine from each of three organizations*

Organization A			Organization B			Organization C		
Cross	Observed pollen gametes		Cross	Observed pollen gametes		Cross	Observed pollen gametes	
♀ ♂	d.c.	Total	♀ ♂	d.c.	Total	♀ ♂	d.c.	Total
1 X 2	0	29	15 X 16	0	29	[2]31 X 32	5	30
[2]3 X 2	0	30	17 X 16	0	28	[2]33 X 32	7	30
[2]4 X 5	0	30	[2]18 X 19	0	20	[2]34 X 31	0	30
6 X 5	0	27	20 X 21	0	22	[2]35 X 31	1	30
7 X 8	0	28	15 X 22	0	30	[2]36 X 35	2	30
9 X 8	0	28	23 X 18	0	30	[2]3 X 35	0	30
10 X 11	0	28	24 X 25	0	29	[2]3 X 37	2	30
12 X 11	0	26	[2]26 X 27	0	30	[2]38 X 39	23	30
13 X 14	0	30	28 X 27	12	30	[2]40 X 41	16	30
7 X 14	0	30	[2]29 X 30	0	21	[2]30 X 39	14	30

[1] Detected pollen contaminants (d.c.) are pollen gametes with an allele at one or more of six isozyme loci *not* carried by the supposed pollen parent involved in the cross.

[2] Those clones used as female parents whose genotypes at six isozyme loci were determined from megagametophytes of an independent seed sample (see text for details).

FECTIVENESS OF OPEN-LLINATION TO PRODUCE ED OF SPECIFIC CROSSES

To avoid costly control-pollinations, alternate methods producing hybrid seed or seed of outstanding specific nbinations have been sought. Among the possibilities wind-pollinated two-clone (or two-species) seed or-ırds (Hyun 1976, Wright 1976) or supplemental mass lination (Little and Trew 1977, Wakeley and others 55, Woessner and Franklin 1973). If the isozyme makeup parents is sufficiently different, crosses between and hin parents can be distinguished. Isozymes, therefore, help to determine the effectiveness of such alternatives.

The isozyme approach was used to estimate the propor-n of hybrid seed obtained when unbagged female wers of pitch pine were mass pollinated with pollen xes from loblolly pine parents.[4] An isozyme gene marker s found in high frequency in the pollen mix but was rare ıny pitch pine source. On the basis of the proportion of len pool gametes of mass-pollinated clones carrying this rker, the proportion of hybrid seed was estimated to ge from 2 to 42 percent (averaging 16 percent) for six nes. A nearly identical mean percentage (17 percent) of rids was found for the progeny of these clones by ring 1-year-old seedlings in the nursery into hybrid and ıhybrid classes on the basis of their stem and foliage racteristics.[5] Because the isozyme technique determines extent of hybrid seed set before nursery establishment, y the seed of clones with high hybrid seed percentages d be sown.

SCUSSION AND CONCLUSIONS

The preceding examples are but a few of the many sible uses of isozymes in applied tree-breeding pro-ms. Although these applications can be invaluable to tree breeder, their practical implementation will de-d on a cost-benefit analysis. The ability to better ermine and maintain the true identity of breeding erials can only be assessed relative to the probability of ors under current breeding technology. As seen in the trolled crosses, this may vary widely among organiza-ıs. Even if error in the handling of breeding materials is relatively small, its effect on reduction of genetic gains kely to be magnified in advanced generation breeding. intaining the identity of breeding materials, therefore, become increasingly important in the future.

Although costs of isozyme analyses will vary substan-y among laboratories, it is helpful to provide some rough estimates. For instance, I have found that processing from 100 to 150 seed tissue extracts by using horizontal starch gel electrophoresis (Conkle 1972) on 1 working day is about maximum for a full-time technician with a half-time assistant to help prepare plants, wash dishes, and do other required tasks. A laboratory with this capability can be equipped for less than $15,000 (including large glass door refrigerator, power supplies, incubator, balance, pH meter, plexiglas gel forms and buffer trays, and miscellaneous glassware and supplies). This estimate assumes a standard laboratory with piped-in distilled water.

For the enzymes normally analyzed, our daily cost of chemicals and supplies averages about $40. With 1 day's run, we can assess the genetic makeup of 9 to 14 parent trees at 10 to 15 loci or analyze from 25 to 30 progeny each from 1.5 to 2.5 controlled crosses for the same number of loci. We can genetically identify a clone for $3 to $5 and determine the validity of a controlled cross for $15 to $25. Although these figures do not include labor, utilities, or depreciation on equipment, at even double the costs, they seem fairly reasonable compared with other expenses normally incurred in a tree-improvement program (Porterfield 1974).

I am not suggesting that it is economically feasible or prudent for most individual organizations to establish their own electrophoresis laboratories at this time. The potential benefits of isozyme analyses in breeding programs, however, seem great enough for research units of larger organizations and tree-improvement cooperatives to consider establishing such laboratories soon. Because of the long generation times faced by most tree breeders, we can hardly afford not to seriously consider isozyme analyses for increasing breeding efficiency.

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Retrieval Terms: forest tree breeding, isozymes, genetic variation, North America, symposia

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FOCUS: a fire management planning system— final report

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FOCUS: a fire management planning system— final report

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CONTENTS

Introduction 1
1. FOCUS and Fire Planning 2
  1.1 System Validity and Usefulness 2
  1.2 FOCUS Cost Effectiveness 3
2. FOCUS System Overview 3
  2.1 System Assumptions 4
  2.2 Submodels 4
  2.3 Validation and Sensitivity Analyses 5
3. Fire Suppression Module 5
  3.1 Fire Occurrence 8
  3.2 Generating the Resource Arrival Sequences 9
  3.3 Dispatching Calculations 12
  3.4 Fire Attack Calculations 13
  3.5 Mop-up Calculations 16
  3.6 Suppression Module Output 17
4. Cost Module 18
  4.1 Assumptions and Limitations 18
  4.2 Input Data Requirements 20
  4.3 Output Descriptions 21
5. Large Fire Gaming 24
  5.1 Input Requirements 25
  5.2 Output Summaries 25
  5.3 Deviating from Established Procedure 26
6. System Support Programs 27
7. Application 28
  7.1 User Requirements 28
  7.2 Implementing FOCUS: Principal Tasks 29
  7.3 FOCUS Cost-Effectiveness Evaluations 32
Literature Cited 33

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FOREWORD

The Forest Service, U.S. Department of Agriculture, maintains what is generally recognized as the world's largest and most efficient fire control organization. It is also the world's most expensive one. Current expenditures for forest fire control now exceed $200 million annually—and the costs continue to climb (Gibson and others 1976).

In 1975, the U.S. Office of Management and Budget queried the Chief of the Forest Service about improved efficiency in fire control: How much did real fire management costs rise from 1964 to 1975, and why? What practices and procedures are best, given an evaluation of appropriate costs and results? Are management procedures capable of selecting appropriate strategies and limiting fire fund use to approved activities (USDA Forest Service 1977b)? Clearly, anything to increase fire management and organizational efficiency potentially could save millions of dollars in public funds.

Historically, the Forest Service has operated under a series of 5-year planning programs, each directed to developing the best possible fire control organization for its time; however, these programs produced only a single plan with no procedure for evaluation of its implementation. A method to quantitatively evaluate the effectiveness of alternative plans in terms of cost/benefit was urgently needed. A modeling framework was required whereby the forestry planner could assess organizational resources—personnel, equipment, transportation—in a variety of configurations and thereby deploy those resources in the most efficient and cost-effective manner.

Such concerns were uppermost when, in 1970, members of the Forest Service's Southwestern Region approached the Pacific Southwest Forest and Range Experiment Station's research staff, at Riverside, California, with a management problem: How to plan an organization to cope with the incidence of high fire occurrence in low value areas that, in turn, pose a threat to adjacent high value areas. Contributing to the problem were the intrinsically low land values that prevented justification of a strong fire organization. A modeling framework ideally could show the relationship of the spread of fire risk between these areas. This would allow land planning management to rank its concerns—suppression, detection, prevention, hazard reduction, and fuel treatment—by priority and allocate its resources accordingly.

The implications of such a program on the national level were not lost. The relationship of fire occurrence patterns to values at risk is one issue confronting forestry management nationwide that could benefit from such a program. The challenge to develop a fire management project of this scope was to become the inaugural investigation of the Fire Management Systems Research Unit, then a newly formed group at the Station's Forest Fire Laboratory, at Riverside, consisting of operations research analysts, mathematicians, computer programmers, and foresters.

Several approaches were considered, including mathematical analysis techniques such as linear programming; however, systems designers felt that a simulation model would be far more practical. The information needed to support a mathematical approach was lacking, but enough was known about the problem that simulation appeared to be a feasible alternative. This led directly to the development of FOCUS (Fire Operational Characteristics Using Simulation).

The development of FOCUS benefited at the onset from the cooperation of various Forest Service units at its 1972 fire planning conference. It was there that representatives of the Division of Forest Fire Research met with the Division of Fire Control and all Forest Service regional fire chiefs. The principal objective was to define the methods and scheduling for reorganizing fire control planning programs within the National Forest System with particular attention to fuel and fire spread models, the National Fire Danger Rating System, fire simulation models, and fire control planning technology. It was agreed that FOCUS would support this national planning effort.

The Bureau of Land Management and the National Park Service, U.S. Department of Interior, and the various State fire protection organizations also indicated strong interest and willingness to cooperate in the proposed development. The California Department of Forestry became an enthusiastic supporter, providing financial as well as advisory assistance throughout the FOCUS development effort.

The initial FOCUS design was ambitious. It envisioned a fully developed, probabilistic computer simulation model that included fire start generation, detection, prevention, and large fire modeling capability (Storey 1972). The fire generation system was to have the capability of generating both man-caused and lightning fires as they would have occurred in nature (Bjornsen and Chase 1971). The model builders recognized that such a comprehensive program would require large quantities of data. An early design feature, therefore, was a system to automate data input as much as possible.

In addition to the technical aspects of computer simulation, several key elements were incorporated that facilitated design capability:

- The FOCUS design was modular. Major system parts were modules that could operate independently of or in cooperation with other modules.

This FOCUS software design feature was particularly useful when revising the program.

- Close user liaison was utilized from the start. Throughout the life of the FOCUS project, liaison officers—personnel familiar with fire control—ensured that the system represented real world concerns. The liaison officers also provided management leadership in the development of the user manuals and system documentation vital to operational testing.
- The FOCUS effort was guided by a steering committee comprised of representatives of the Forest Service's National Forest System and State and Private Forestry; Bureau of Land Management; and individual States—each with a strong fire background. These representatives reviewed FOCUS progress and made recommendations for future development. Because computer simulation was relatively new to fire planning in the early 1970's, a major role of the steering committee was to transfer information to their home units to ensure successful system implementation.
- Eight test areas, including seven National Forests and one California Department of Forestry ranger unit, were selected as test areas from which data would be supplied and preliminary versions of the model tried out. This cross section was considered representative of all fire problems throughout the nation.

Some modules progressed rapidly, others lagged. It eventually became apparent that if FOCUS was to be completed on schedule, the original model would have to be revised. Consequently, it was decided to develop a deterministic model. A set of several hundred historical fires was adopted, rather than generating fires as originally planned. Also, the fire detection and fire prevention modules would be developed independently and a manual gaming technique would be used in place of a computer-based large fire module.

At the same time, the fire suppression and cost modules were becoming increasingly complex. A comprehensive FOCUS system was to be used nationwide. Consequently, the model had to accommodate any conceivable fire control operation. As new techniques such as rapelling from helicopters were developed, they were incorporated into FOCUS.

By mid-1975, system developers prepared for FOCUS technology transfer. Teams from the Forest Service and other Federal and State agencies met at Riverside for a 2-week training session. Armed with the new technology, the teams returned to their respective units, and over the next 2 years were able to successfully operate the FOCUS system. Some regions were outstandingly creative in their application and interpretation of FOCUS.

Following the technology transfer, the Forest Service Research Branch began reducing its role. By October 1978, all user manuals were prepared and the computer program was reasonably debugged. Most importantly, the Forest Service's Aviation and Fire Management Staff recruited a three-member team with the principal responsibilities of providing user support and maintaining FOCUS for the National Forest System and State and Private Forestry and a national training program was started (USDA Forest Service 1978b). Computer access to FOCUS was converted to the U.S. Department of Agriculture's Computer Center at Fort Collins, Colorado. By the end of 1978, about 30 units from the Forest Service, the Bureau of Land Management, and several States had some experience testing or applying FOCUS.

In March 1979, FOCUS was established as an operational system by National Forest Systems, and a Forest Service Manual Amendment (No. 59) was issued in June 1979 to provide national policy and direction for the use of FOCUS.

Today the Forest Service is beginning to realize a return on its investment. From the standpoint of operational planning costs, FOCUS has proven cost effective. The FOCUS system provides substantially more savings than those derived from other existing techniques to measure fixed presuppression costs, variable suppression costs, and damages.

Historically, the Forest Service has taken several approaches to the problem of organizational efficiency and resource management (Lowry 1965). Not the least of these is experience and intuition which, during the past 75 years, have helped create the world's most effective, albeit expensive, fire control organization (*fig. 1*). But this system prevented managers from testing alternatives and yielded only a sketchy idea about cost/benefit relationships.

Trial and error have also been part of the process in the past. And while these techniques may be effective in theory, they are inefficient in the practice of fire control. Because of variability from one fire season to another, it may take 5 to 10 years to evaluate a fire plan. Conditions change over this period of time and costs and damages may be expensive.

Another approach to forestry issues has been mathematical modeling, including linear programming. Examples are Timber RAM, a resource allocation model to aid timber management; and VIEWIT, a recreational planning model. Unfortunately, fire research has not developed to the point that we know all the mathematical interrelationships that exist, including the total combustion process, fire effects, and suppression activities, to effectively develop linear programming or other mathematical models.

Fire control planners have, however, a general knowledge of the probabilities of certain fire-related events and sufficient understanding of actual fire processes to allow these aspects of fire planning to be computer simulated. Supplied with this knowledge, the Station's Fire Management Systems Research Unit, at the Forest Fire Laboratory, Riverside, California, developed the large-scale computer simulation model called FOCUS (*F*ire *O*perational *C*haracteristics *U*sing *S*imulation).

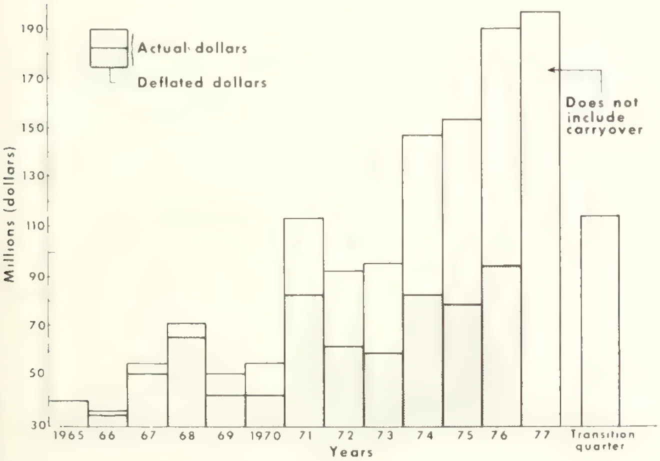

Figure 1—Total expenditures by the Forest Service in forest fire control and suppression now exceed $200 million annually.

Mathematical models may be categorized as either deterministic or probabilistic. Deterministic models are devoid of uncertainty and can predict exact changes (McMillan and Gonzalez 1968). FOCUS is basically deterministic. Conversely, probabilistic, or stochastic, models reject such certainty and proceed in a more random manner. Ideally, FOCUS should have been probabilistic, since uncertainty is more the rule than the exception; however, the FOCUS suppression model is designed to represent a complex process that is not amenable to overall representation by a mathematical model. Operations research workers and others (Hillier and Lieberman 1968, ch. 14) generally recognize that simulation often provides the only practical approach to analyzing such a process. Simulation is particularly applicable when a process can be divided into a logical sequence of subordinate operations, each of which can be analyzed by a mathematical or computer model. The FOCUS fire suppression model represents such a process.

Statistical validation of the FOCUS simulation model is not practical for two reasons: first, the model is basically deterministic, though it does contain stochastic aspects—particularly in simulated fire occurrence; second, data from the actual process generally are not available for comparison, except in a limited sense. Input to FOCUS is quite extensive, involving literally thousands of data items, a large percentage of which are derived from imprecise measurements or estimates of physical parameters. It would therefore be impractical to attempt stochastic interpretations of many of these items, particularly in the absence of sufficient data on which to base probability distributions. Beyond this, computer costs of repeated FOCUS runs to obtain stochastic outputs would preclude its use by many users.[1] Instructions for FOCUS data preparation usually require that average or typical values be provided for data parameters. In tests to date, users have had little trouble giving such estimates. (As hoped for by the FOCUS developers, some users have conducted inquiries aimed at correcting data deficiencies.) Thus, even though the model is deterministic, it could be termed an "expected value" model.

Input to the model simulating fire occurrence usually includes hypothetical fire data for several "seasons" based on historical fire reports. Model output is ordinarily aggregated and printed by season where variability between seasons is desired. Seasons are selected from the past 10 years or more for their relevance to specific fire problems. This procedure comprises many of the elements of a stochastic input for a critical set of data. An historical season of fires is certainly a sample of the population of fire seasons. "Importance sampling" (Hillier and Lieberman 1968, ch. 14) is used, however informally, to give system performance estimates that are much improved over a purely random sampling procedure such as selecting historical fire seasons at random.

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[1] Computer costs per run have typically been $20-$50. If the desired statistical reliability could be obtained using 10 iterations (probably a low estimate), users would be faced with computer costs in the hundreds of dollars per alternative evaluated.

The FOCUS computer simulation model offers several advantages over other methods of fire planning:

- An attractive management tool to evaluate objectively various planning schemes
- Rapid evaluation of alternative plans
- Simultaneous consideration of numerous data variables and the insights derived from correlating these
- The elimination of human bias in evaluating several plans or in scrutinizing the elements of a single plan (Naylor and others 1966).

In using the FOCUS system, experience has shown that from $20-$60 thousand, including labor, computer time, travel, and overhead, may be required to gather all information needed to make the first few successful and realistic runs. Considerable time is required to collect and debug data and to refine the input variable so that FOCUS output represents realistic values. The expenditure of time and money corresponds roughly to that spent in previous planning efforts.

1. FOCUS AND FIRE PLANNING

FOCUS is designed to evaluate alternatives provided by the fire planner (Davis and Irwin 1976). It is not self-determining in the sense that it develops its own alternatives, nor is it an "optimum-seeking" model. For example, the fire manager tests two or more possible fire plans for his protection unit, evaluates these in the FOCUS system along with other constraints such as political considerations, then selects and implements that plan most closely approximating existing needs.

FOCUS can also be applied to make minor adjustments or pursue leads revealed in preliminary FOCUS runs. In this manner, the user may continue to make minor changes (fine tune) until achieving the best mix of available resources, including labor, equipment, transportation network, and other capital facilities.

Previous systems provided no opportunity to test alternatives. FOCUS, however, provides multiple tests and evaluations to the skilled analyst at minimum cost. Many have viewed the initial cost of the system as a capital investment, with the profit margin increasing in proportion to system use.

FOCUS simulation has been termed "what-if planning." A fire manager may ask, "What if I change the location of an air attack base? What if my budget is cut by 10 percent? What if I use prescribed fire on selected areas on a 3-year cycle?" Any of a multitude of possible alternatives can be tested in a matter of hours. It must be emphasized, however, that FOCUS is an organizational planning tool—it is not designed to help fight fires; although portions of the program, such as the transportation network, are being used outside of FOCUS on actual fires using commercial time-sharing systems. Nor does the availability of computers and the use of operations research automatically provide an adequate simulation technique. Proper systems analysis must account for the total dynamics of a problem. If basic data are not available or proven, the value of the resultant output is weakened (Drake and others 1972). Because of its very large data input and output, FOCUS can be operated only on very large computers with high speed input-output equipment.

The FOCUS system provides a unique research opportunity to evaluate the effectiveness of alternate fire suppression organizations at different budget levels and to define the frontier of efficient organizations (*fig. 2*).

1.1 System Validity and Usefulness

Simulation results have been validated against real values in two ways. First, statistics and distributions of

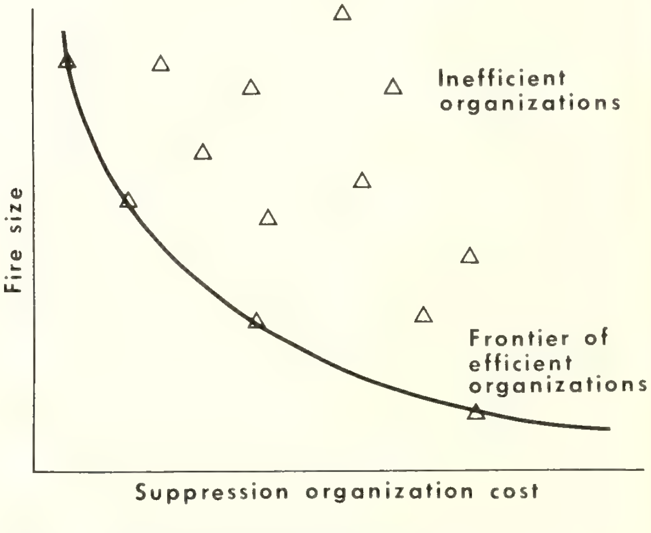

Figure 2—Estimation of the frontier of efficient fire suppression organizations by using effectiveness-cost evaluations (all other conditions held constant).

key variables have been compared, where possible; such checks have been made but remain unpublished. Second, systems users have performed benchmark testing to ensure the accuracy of data inputs and the compatibility of the simulation with suppression operations for their particular planning units.

This simulation validation means not only that the model is a faithful representation but that it also is a useful fire planning tool: Does it provide the planner with the information needed? Are personnel adequately trained to perform the FOCUS tasks within the controls of budget and time? The answers vary among the nearly 30 agencies that have tested FOCUS; however, three-fourths of the users have been able to produce reliable FOCUS runs for their units. An estimated 50 percent of these users have made crucial management decisions, involving millions of dollars, that will affect their organizations for years to come. In addition, the Forest Service used FOCUS in early 1979 in a major budget and policy analysis, using six National Forests. The analysis may help determine budget levels and the balance between fuel management, prevention, and suppression expenditures.

1.2 *FOCUS Cost Effectiveness*

A common concern of FOCUS users is the cost effectiveness of the system in terms of dollars and reductions in fire loss. Both of these savings are difficult to assess, since they reflect the result of a series of events. Let us demonstrate this point hypothetically.

Assume that a FOCUS program costs $5,000 to analyze a given transportation system. The study shows that if a $100,000 road link were built, a major savings will be realized in loss and suppression costs, averaging $50,000 for 10 years or a present worth of $307,228 at 10 percent interest. This looks like a 60:1 return on the initial FOCUS investment of $5,000—clearly cost effective. But the forest engineer points out that it is a 3:1 investment on road construction and the fire management officer points out that it is a rather large return on money invested in his salary while making and implementing the decision. Then how do these savings relate to FOCUS? The size of some of these returns can be based on various levels of FOCUS investments (*fig. 3*). In a sense, the values reflect the cost effectiveness of FOCUS if no significant investment were needed to achieve the savings. If investments must be made to achieve the savings, then FOCUS can only share in the cost effective relationship.

The object is that FOCUS should be viewed as the key for making management decisions with very high payoff values. Those payoff values, in turn, are the result of several factors entering into the cost effectiveness equation.

2. FOCUS SYSTEM OVERVIEW

Input to the FOCUS model includes a set of several hundred, perhaps thousands, of fires that actually occurred. These fires are selected from fire seasons representative of the unit's workload, usually including one extreme season and one or more average seasons. Fires must be considered on a yearly basis, since weather considerations and multiple fire situations are important in FOCUS analysis. Computer modeling simulates the start of real world fires, including time and location. The model assumes that fires spread at the same rate, within the same fuel type, and on the same terrain, as actually occurred.

Each simulated fire starts to spread in an ellipse, suppression forces are rushed over the appropriate transportation network, ground transport is by the forest road and trail system, and helicopters and fixed-wing aircraft use the most direct air route. As they arrive on the scene, crews are given assignments appropriate to conditions of fuel, topography, and fire behavior. As portions of the fire ellipse are held by control forces, its shape is greatly modified. The growing ellipse is a suitable simulation model of the spread of a fire burning within uniform con-

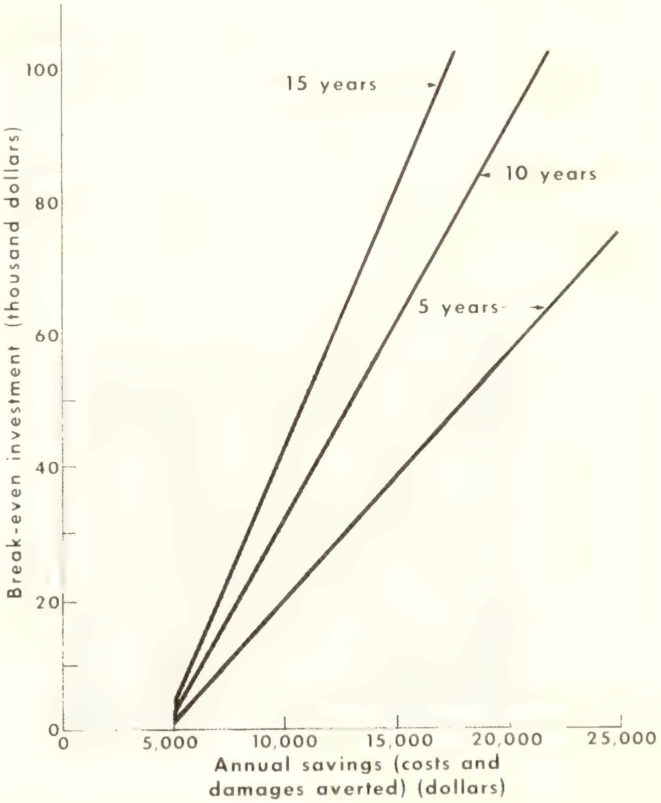

Figure 3—Annual savings needed to cover initial investment costs in using FOCUS over periods of 5, 10, and 15 years.

ditions of fuel topography and weather (Pirsko 1961). A large fire, however, will soon burn into different fuel, terrain, and weather conditions, and the perimeter may no longer approximate an ellipse. Those few fires, say 1 in 50 or so, that exceed user-defined size or suppression time parameters are called escapes. These escapes are analyzed by a team of local experts who game them by following a precise set of rules and instructions, as frequently done in advanced fire management schools. The gamers are given a variety of information, including maps and computer printouts showing the time of escape, suppression forces on the fire and en route, and weather prediction for the next 4 days. Both the computer and the gamers calculate cost, damages, and acres burned. Each candidate plan is tested against the same set of fires. The results are expressed in terms of cost effectiveness. Cost elements consist of the actual fixed and variable cost of the planning unit's protection organization. At present, effectiveness is considered the difference in cost and damages between the current and proposed plan. Damage values can be taken from the damage potential classes used in the Forest Service National Fire Planning Effort of 1972[2] or can be established by the user.

Although the original FOCUS model was intended to have basic data arranged in a cellular form and be entered in input to the computer automatically, the current version uses data obtained from a variety of sources in various formats, including fire reports, vegetation and value class maps, and a series of magnetic computer tapes giving elevation for points located 208 feet (63.4 m) apart over the test area (Podufaly 1969). Only portions are input automatically.

Most data can be obtained from existing records, but certain information, such as travel times for each of the transportation systems, must be measured or estimated. Times are determined for three vehicle weight classes and for foot travel on trails, in both directions for each segment of the road and trail system.

Agency procedures and rules, such as dispatch action under various conditions, must also be analyzed for computer entry. These dispatch rules also show how forces not financed as part of the agency's fire management organization are utilized, when or on what kind of fires they are called, and how long it takes to dispatch them.

2.1 System Assumptions

The following assumptions relate to the FOCUS model in general (assumptions which apply to specific modules are discussed later):

- FOCUS uses a historical set of fires, usually from the past decade, assuming that the same pattern and distribution will occur for the planning period, say the next 5 years. This assumption is not exactly correct because human activity and fuel conditions are not constant. Consequently, FOCUS users are encouraged to select their set of historical fires from a base that is as current as possible. Also, FOCUS provides an opportunity to update data, such as spread rates and resistance to control, based on known changes in fuel condition. Modifying and updating FOCUS is relatively quick and inexpensive.
- Although no fire spreads in a neat elliptical pattern, the elliptical spread model reflects fairly realistically what actually takes place.
- FOCUS does not measure the real world precisely. For example, no one breaks a leg, trucks do not blow out tires, division bosses do not get lost. But since all candidate plans being evaluated are tested against the same set of conditions—even though they are not a perfect match for the real world—the ranking of the various candidate plans will be relatively accurate.
- FOCUS is really a system for comparing alternate plans for initial attack, first reinforcement actions, and use of existing cooperators. FOCUS is not designed to evaluate and follow up reinforcement action on major campaign fires. Nor does FOCUS normally account for back-up forces that might come from other States, far-away National Forests, or organizations not typically used such as the military. (Gamers may want to include such resources on escaped fires.)

2.2 Submodels

The FOCUS model at its highest level of organization comprises the data collection and verification subsystem which uses both manual and computer methods (ch. 6); the suppression module (ch. 3) and cost module (ch. 4) computer programs; and the large fire gaming manual procedure (ch. 5).

Data are assembled where possible from existing computer-based files, otherwise manually from maps or other graphic sources. Computer programs are available for data assembly and checking (ch. 6). In addition to the computerized data checking procedures, users are instructed to examine initial program outputs carefully (ch. 2) to uncover data errors such as omissions or misrepresentations which do not have the kinds of logical inconsistencies which can be detected by the data checking programs.

The suppression module comprises two computer programs—STORETT and RUNPLAN—that are run sequentially. STORETT uses road network data along with simulated fire and ground unit base locations to calculate and store in the computer the travel times from bases to fires. RUNPLAN uses the ground unit travel times with other data to simulate and print results of individual fire attacks and to accumulate the results for tabular listing of important quantities. Individual fire results also are stored for later use in the cost module.

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[2] USDA Forest Service. 1972. National fire planning instructions (draft). Washington, D.C.

The cost module consists of two programs. SMOKEY I reads and prints the costing data, checks for errors, and stores the data for use in SMOKEY II. The latter program uses the data from SMOKEY I and from the suppression module to calculate and print suppression costs and damage values for the fires. These results can be printed in a variety of optional formats.

Inputs to the large fire gaming procedure (ch. 5) are provided by the suppression module output. The parameters provided are the size and time that each "escaped" fire exceeded escape conditions, and the list of suppression resources which the suppression module has dispatched to the fire along with arrival times. The length of fireline constructed, by escape time, also is provided. The large-fire gamers thus have a set of initial conditions for beginning the gaming procedure which is completely consistent with the operation of the suppression module.

Computer and personnel cost considerations preclude the performance of iterations between suppression module execution and large fire gaming which would be required to reflect the large fire gaming results back into the suppression module. The effects of this assumption are mitigated by two considerations. First, in real life, many resources for large fire suppression ordinarily are drawn from sources outside the local organization for which the FOCUS suppression module data base is designed. Second, the impact of large fire operations is estimated within the "mop-up" section of the suppression module (see *sec. 3.5*) by tying up the local resources dispatched to the fire for set lengths of time, depending on the kind of units involved.

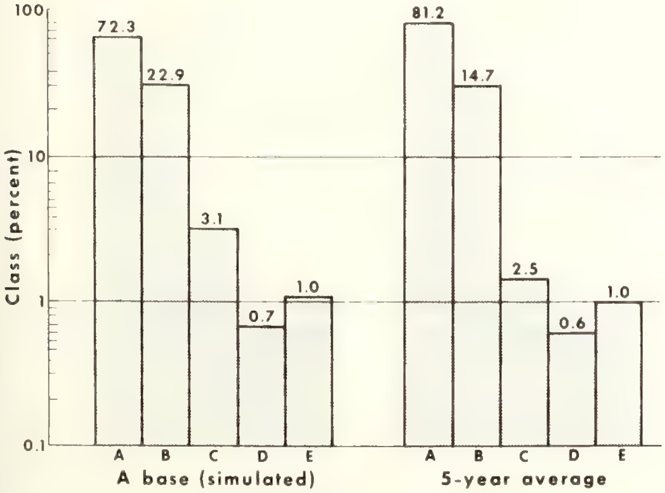


Figure 4—Fire size and frequency simulated by FOCUS were comparable to that based on 5 years of historical records.

2.3 Validation and Sensitivity Analyses

2.3.1 Validation

A statistical chi-square test determined the goodness-of-fit of the actual data (number and size of fires from reports) compared to theoretical distributions from FOCUS. The conclusion was that FOCUS adequately simulates frequency and sizes of fires from historical records (*fig. 4*).

Expert evaluation of FOCUS output was also supplied by a team of experts familiar with the unit's area. Final size and suppression action taken were examined for reasonableness of fit. Types and composition of computer material and scenarios describing suppression action were judged for reasonableness and usefulness to fire managers. FOCUS output and scenarios were found to be generally reasonable and useful.

2.3.2 Sensitivity Analysis

The sensitivity of FOCUS to changes within fire plans was another important concern. Because the Forest Service plans on the basis of worst fire situations (90th percentile), organizational overstrength might be expected most of the time. Thus, wild fluctuations in FOCUS output related to a small plan change would not be realistic. Results of a sensitivity test in which plans were changed while holding all other variables constant showed that FOCUS produced reasonable fluctuations in frequency of fire sizes, thereby verifying this aspect of FOCUS.

Sensitivity analysis can also be used to determine the preciseness of data required to minimize data collection and preparation. This procedure has not been used because of insufficient time but is strongly recommended for the future.

3. FIRE SUPPRESSION MODULE

The FOCUS Suppression Module is a computer simulation model which represents the functioning of a wildland fire protection organization in response to simulated fire occurrences (*fig. 5*). The basic model simulates attacks on single or multiple fires, but it is intended as a planning tool on the seasonal or yearly time scale. As such, the model is designed to evaluate the overall performance of a fire suppression organization over one or more seasons in response to a large number of fires.

For each simulated fire start, the model generates a list of alternative resource arrivals at the fire. This list includes ground transported units such as crews, engines and tractors, as well as air units—helicopter attack crews, smokejumpers, or air tankers. Each such resource is

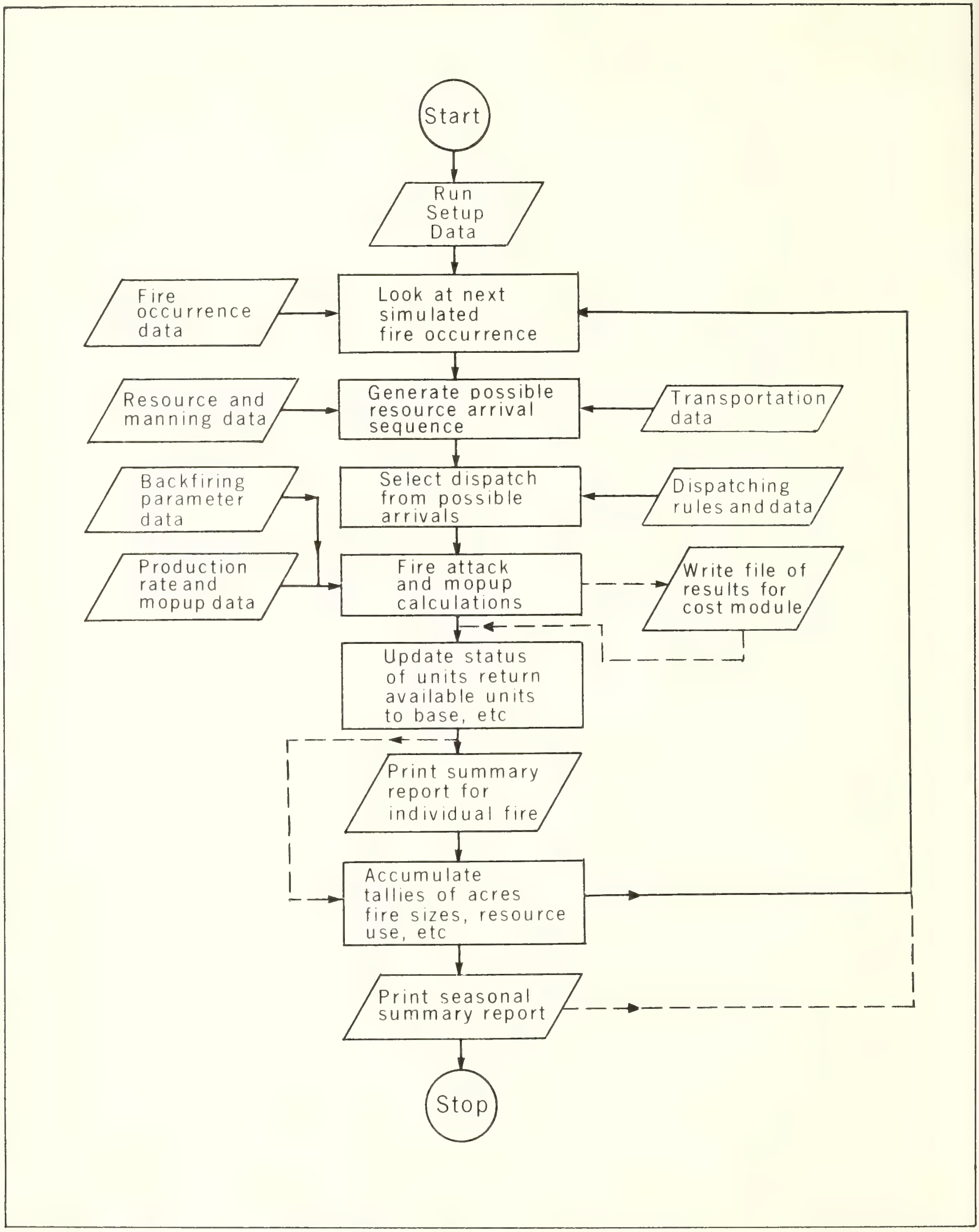

Start
Run Setup Data
Fire occurrence data
Look at next simulated fire occurrence
Resource and manning data
Generate possible resource arrival sequence
Transportation data
Backfiring parameter data
Select dispatch from possible arrivals
Dispatching rules and data
Production rate and mopup data
Fire attack and mopup calculations
Write file of results for cost module
Update status of units return available units to base, etc
Print summary report for individual fire
Accumulate tallies of acres fire sizes, resource use, etc
Print seasonal summary report
Stop

Figure 5—FOCUS suppression module simulates attacks on single or multiple fires.

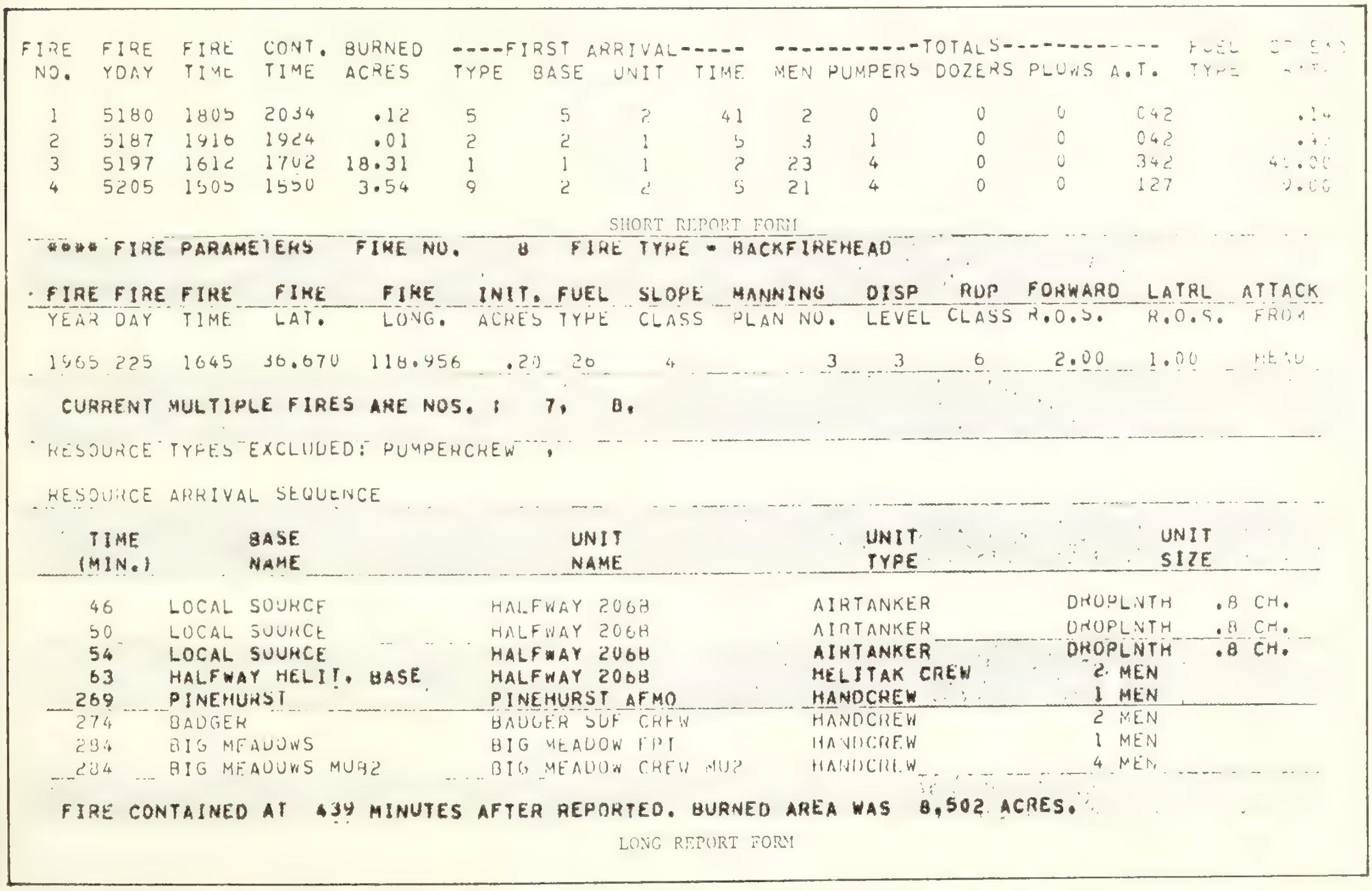
defined by user-supplied data. Certain kinds of units may not be included if they are prohibited from or cannot operate in the fire area, or if they are air units and the simulated time of day is after dark.

A subset of the possible arrival list is selected for dispatch using one of two dispatching schemes, or a combination thereof: Threat response dispatching, intended to represent the procedures of a knowledgeable dispatcher aided by some information about the fire and conditions at the fire site; and preplanned area dispatching, a scheme that uses dispatch levels for various combinations of units which are planned in advance, based on geographical areas and fire danger levels.

Once the dispatch to the fire has been selected, the results of the fire attack are estimated. A simple table is used to estimate final size and time of containment for fires contained at less than 10 acres and within 2 hours of the initial attack. A more complex calculation is used to simulate the attacks on fires which exceed either of these limits. Crews, tractor plows, and bulldozers construct a fireline at rates which depend on the kind of unit, fuel type, slope, and unit size. Air tanker retardant drops are linear fire barriers, with effective length dependent on quantity of retardant, fuel type, and fire rate of spread.

The fire list may contain nonspreading fires if a user considers that these form a significant part of the protection workload. A nonspreading fire may be one of five types: structure, vehicle, improvement, refuse, or false alarm. For each of these types, a typical dispatch is specified using the preplanned area dispatch scheme. Units dispatched to nonspreading fires are held for set times, then returned to their bases. No attempt is made to simulate attacks on nonspreading fires beyond this rudimentary level.

The users can choose to print a summary report for each fire in a seasonal list. A short one-line form or a longer form which gives complete information about the fire parameters, the resource arrivals, and the outcome of the attack may be used (*fig. 6*). Fires which exceed an escape size or escape time as specified by the user are carried no further in the computations. Results for these fires are printed on the long form, giving information about time and size at escape and length of held fireline completed in the calculations. Calculations normally terminate when no units are available for dispatch to a fire. These fires are labeled "no-dispatch" and the fire parameters are printed with an estimate of when and how the fire would reach escape conditions, if not attacked. Nonspreading fires are appropriately labeled, and the dispatched units are listed along with the time they are held on the fire.



```
FIRE  FIRE  FIRE  CONT.  BURNED  ----FIRST ARRIVAL-----  -----------TOTALS------------  FUEL    OF ESC
 NO.  YDAY  TIME  TIME   ACRES   TYPE  BASE  UNIT  TIME  MEN PUMPERS DOZERS PLOWS A.T.  TYPE

  1   5180  1805  2034     .12    5     5     2     41    2    0       0      0    042            .14
  2   5187  1916  1924     .01    2     2     1      5    3    1       0      0    042            .4
  3   5197  1612  1702   18.31    1     1     1      2   23    4       0      0    342          40.00
  4   5205  1505  1550    3.54    9     2     2      5   21    4       0      0    127           9.00
```

SHORT REPORT FORM

```
**** FIRE PARAMETERS   FIRE NO.    8   FIRE TYPE * BACKFIREHEAD

 FIRE FIRE FIRE   FIRE     FIRE    INIT. FUEL  SLOPE  MANNING   DISP   RDP  FORWARD  LATRL  ATTACK
 YEAR DAY  TIME   LAT.     LONG.   ACRES TYPE  CLASS  PLAN NO.  LEVEL CLASS R.O.S.  R.O.S.  FROM

 1965 225  1645  36.670  118.956    .20  26      4         3       3     6    2.00    1.00   HEAD

  CURRENT MULTIPLE FIRES ARE NOS. :   7,   8,

 RESOURCE TYPES EXCLUDED: PUMPERCREW   ,

 RESOURCE ARRIVAL SEQUENCE

   TIME        BASE                    UNIT                   UNIT                 UNIT
  (MIN.)       NAME                    NAME                   TYPE                 SIZE

    46    LOCAL SOURCE         HALFWAY 2068            AIRTANKER         DROPLNTH   .8 CH.
    50    LOCAL SOURCE         HALFWAY 2068            AIRTANKER         DROPLNTH   .8 CH.
    54    LOCAL SOURCE         HALFWAY 2068            AIRTANKER         DROPLNTH   .8 CH.
    63    HALFWAY HELIT. BASE  HALFWAY 2068            HELITAK CREW        2 MEN
   269    PINEHURST            PINEHURST AFMO          HANDCREW            1 MEN
   274    BADGER               BADGER SUF CREW         HANDCREW            2 MEN
   284    BIG MEADOWS          BIG MEADOW FPT          HANDCREW            1 MEN
   284    BIG MEADOWS MU82     BIG MEADOW CREW MU2     HANDCREW            4 MEN

 FIRE CONTAINED AT  439 MINUTES AFTER REPORTED. BURNED AREA WAS  8,502 ACRES.
```

LONG REPORT FORM

Figure 6—Example of supression module output: individual fires.

```
N U M B E R / P E R C E N T   O F   C O N T A I N E D
F I R E S
=====================================================
|         |                                 ||             |
| R.D.P.  |        S I Z E   C L A S S      ||             |
| CLASS   |-----------|----------|----------||   TOTALS    |
|         |  --A--    |  --B--   |  --C--   ||           --|
|=========================================================|
|         |           |          |          ||             |
|    1    |    0/ 0   |   0/ 0   |   0/ 0   ||      0/ 0   |
|         |           |          |          ||             |
|=========================================================|
|         |           |          |          ||             |
|    2    |    0/ 0   |   0/ 0   |   0/ 0   ||      0/ 0   |
|         |           |          |          ||             |
|=========================================================|
|         |           |          |          ||             |
|    3    |    0/ 0   |   0/ 0   |   0/ 0   ||      0/ 0   |
|         |           |          |          ||             |
|=========================================================|
|         |           |          |          ||             |
|    4    |    2/17   |   2/17   |   1/ 8   ||      5/42   |
|         |           |          |          ||             |
|=========================================================|
|         |           |          |          ||             |
|    5    |    1/ 8   |   2/17   |   0/ 0   ||      3/25   |
|         |           |          |          ||             |
|=========================================================|
|         |           |          |          ||             |
|    6    |    1/ 8   |   2/17   |   0/ 0   ||      3/25   |
|         |           |          |          ||             |
|=========================================================|
|         |           |          |          ||             |
|    7    |    0/ 0   |   0/ 0   |   0/ 0   ||      0/ 0   |
|         |           |          |          ||             |
|=========================================================|
|=========================================================|
|         |           |          |          ||             |
| TOTALS  |    4/33   |   6/51   |   1/ 8   ||     11/ 92%  |
|         |           |          |          ||             |
=====================================================

NOTE: CLASS C FIRES ARE ALL FIRES LARGER THAN 10 ACRES
      AND SMALLER THAN ESCAPE SIZE. (100.0 ACRES)
```

Figure 7—Example of suppression module output: seasonal summaries.

```
              G R O U N D   U N I T   U S E   T A L L Y
            (NUMBER OF DISPATCHES PER UNIT ON EACH BASE)
                            UNIT NUMBER
              1    2    3    4    5    6    7    8    9   10
BASE  ||=============================================||
 #    ||                                             ||
  1   ||   4    3                                    ||
  2   ||   7    1                                    ||
  3   ||   4                                         ||
  4   ||   0                                         ||
  5   ||   4                                         ||
  6   ||   1                                         ||
  7   ||   0                                         ||
  8   ||   3                                         ||
  9   ||   4                                         ||
 10   ||   1                                         ||
      ||                                             ||
      ||=============================================||

              H E L I C O P T E R   U S E   T A L L Y
            (NUMBER OF TRIPS PER HELICOPTER ON EACH BASE)
                          HELICOPTER NUMBER
              1    2    3    4    5    6    7    8    9   10
BASE  ||=============================================||
 #    ||                                             ||
  1   ||   0    0                                    ||
  2   ||   0    0                                    ||
  3   ||   1    1                                    ||
  4   ||   0    0                                    ||
  5   ||   0    5                                    ||
      ||                                             ||
      ||=============================================||

                     HELICOPTER DISPATCHES
                       COPTER    # FIRES
                          1         1
                          2         6
```

Figure 8—Example of suppression module output: resource-use summaries.

At any point, though usually at the end of a season, tables are generated which summarize the results of contained, escaped, and no-dispatch fires. The number of nonspreading fires is also given. For contained fires, the numbers and percentages of fires in size classes A, B, and C are given. Class A fires have a final burned area of less than 0.25 acre, class B fires between 0.25 and 10 acres, and class C fires between 10 acres and escape size in final area (*fig. 7*). Another table lists the acres burned within the various fire size classes, weighted by resource damage potential class numbers.

A summary is also available that lists the usage for each resource unit including the number of times dispatched, and number of trips for air units (*fig. 8*).

3.1 Fire Occurrence

3.1.1 Planning Assumptions

The fire occurrence data needed for the suppression module consists of a set of data describing each fire. A maximum of 40 data items can be used for each fire, though ordinarily about 20 are employed (USDA Forest Service 1977c, p. B2-B9). These items can be grouped in six categories: identification, geographic, time of occurrence, access, fire behavior, and dispatching factors.

A "special work force" category is also included in the fire data which relates generally to time and location of a fire. The "special work force" entry is used typically to establish evening or weekend crew size changes, or for lightning storm move-up operations.

An early decision in FOCUS development was to base the fire occurrence data on historical descriptions. Early work was based on Forest Service fire reports from the 1960 decade. All information needed for the FOCUS fire occurrence data was on the report forms or could be derived from the recorded items by some reasonable assumptions and procedures. But three major difficulties were found. First, the 1960's data were old by the middle 1970's. Some forest areas had changed in important ways, thus affecting fire occurrence patterns, fuel patterns, and fire behavior. Second, reliability and consistency are variable within specific data items. Third, the Forest Service revised its fire report forms in the early 1970's, eliminating the information about rate of fire spread. Forest Service users who wished to use historical fires from the 1970 decade in order to reflect more current conditions, were required to use other methods to derive the important rate-of-fire-spread data. Several user groups were able to solve this problem to their own satisfaction, but standardized procedures did not materialize. For example, some regions developed spread rate tables based on data such as fuel type and weather. Hopefully, the new Forest Service report form for the 1980's will again contain spread rate information.

The process simulated by the FOCUS suppression module is basically a competition between the ability of suppression forces to build and hold fireline, and the ability of a fire to generate fire perimeter as it spreads. Rate-of-spread assumptions are critical in determining the outcome of this competition. However, the importance of accurate values for spread rates is diminished greatly by two factors. First, spread rate in nature is a stochastic or chance variable. Significant variations can occur due to small changes in location (fuel, topography) and weather factors (wind, relative humidity). It follows that, for a planning use of fire spread as in FOCUS, there is no correct value for a particular hypothetical fire. However, spread rate distributions and significant correlations found in nature must be preserved. The use of historical fire occurrence data ensures that a fire spread rate will be consistent with fuel, slope, and weather factors related to the day, time, and location of the fire.

Exact spread rates are also unimportant because FOCUS is a comparative system. Importantly, planning alternatives must be compared on the basis of one set of consistent, reasonable fire occurrence data. Less important is the exact correspondence of these data to historical fires.

3.1.2 Program Assumptions

A fire workload is a user-supplied set of simulated fire occurrences based generally on historical data. Approximately 20 data items which are used to describe a FOCUS fire apply throughout the course of the simulation. That is, fuel, slope, rate of spread, and other factors are assumed constant for a given fire.

A free-spreading fire is assumed to have an elliptical shape with the fire origin at a focus of the ellipse (*fig. 9*). The length-to-width ratio of the ellipse is one of the fire occurrence data items. *Section 3.4* discusses how suppression action alters the free fire ellipse.

Table 1—*Maximum numbers per planning unit of fire suppression resources*

Resources	Maximum number
Ground bases (fire stations)	100
Helitack bases[1]	30
Prepared helispots	500
Smokejumper bases	10
Air tanker bases	10
Ground units (total per ground base)	10
Hand crews	
Pumper crews (fire trucks)	
Tractor plows	
Bulldozers	
Nurse tankers (water wagons)	
Helicopters[2]	15
Smokejumper transport aircraft	[3]5
Air tankers[2]	15

[1] Helitack bases may be co-located and share men with ground bases.

[2] Dual mode aircraft may be defined as personnel-carrying helicopters for the first trip and helicopter air tankers (helitankers) thereafter.

[3] Per base.

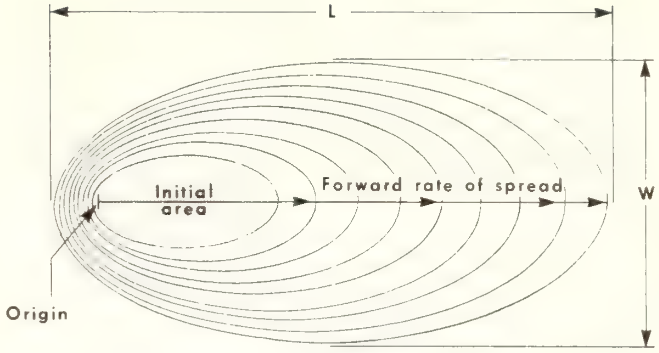


Figure 9—Elliptical fire model is specified by initial area, forward spread rate, and length/width (L/W is constant for all sizes).

3.2 Generating the Resource Arrival Sequences

3.2.1 Planning Assumptions

FOCUS users are required to assemble a set of data which describes the fire resources available for a given fire plan or alternative. These data describe operation bases and eight types of units—ground crews with handtools, pumper crews, tractor plows, bulldozers, helicopter attack crews, smokejumpers, air tankers, and nurse tankers (*table 1*).

For helitack crew operations, the available helicopters must be described, and transport aircraft data are required for smokejumpers. An additional dual mode operation uses an aircraft to deliver crewmen on the first trip, then switches to an air tanker (bucket or water scooping) operation.

Ground Units—The time interval required for ground units (hand and pumper crews, tractors) to arrive at a simulated fire location is the sum of several time increments. Two kinds of time delay can occur before a unit leaves its base. First, a straight getaway time can be specified in the data for each unit. Secondly, a return-to-base time which depends on fire danger level can be used. The latter simulates conditions for backup fire crews working on other projects, but required to stay within a given distance from base, depending on fire danger conditions. Another time increment is actual travel time on the road and trail system from a base to the unloading point, that is the closest point to the fire. Then, unless the fire is next to the road or trail, a final cross-country walking time increment is added. This time is calculated using a level-ground, cross-country walking speed specified by the user. Optionally, if elevation above sea level is provided for roads and fires, a correction in walking speed is calculated to account for the difference in elevation between the unloading point and fire. The total travel is subject to a maximum value that can be specified for units such as those from cooperators which will not respond to fires beyond a certain travel time away from their bases.

The road network data can include up to three travel times over each road segment corresponding to classes of vehicles. Also, two-way travel times must be specified to account for uphill and downhill differences. The computer program determines the best routes from bases to fires to minimize travel times.

Storing base-to-fire travel times on the FOCUS system proves highly cost effective. Subsequent computer runs using all or some of the same base and fire locations can use these stored travel times at a considerable cost saving.

An optional program capability provides for refilling pumpers from local water sources rather than the alternatives of nurse tankers or staying empty. Users can partition the planning area into four sectors and specify an average refill time for pumpers on fires in each sector. This is time from water exhaustion until the pumper is back on the line with a full load of water. In the refill operation, one man is assumed to accompany the pumper while the remaining crew continues to work with handtools, unless otherwise prohibited by a data option. When a nurse tanker arrives at a fire, 5 minutes are assumed for hook-up before empty pumpers at the fire start using the water. A pumper can be specified as a portable pump which obtains water from a nearby source and never runs out of water.

Pumper crews always become hand crews when water is exhausted, unless prohibited by a data option. A data-specified subtype associated with the pumper determines which of three possible hand crew production tables is used.

Helicopter Attack Crews—Crews delivered by helicopter may be actual helicopter attack crews or ground crews. Helicopter attack proceeds from the home base followed by reinforcements from the nearest base to the fire with a suitable crew and facilities. In multiple fire situations, a backlog of demand for a helicopter may build up. In such cases, a helicopter may deliver a partial load to one fire before proceeding to the next. When the helicopter is empty, it will reload at the nonempty base nearest the fire to which it is next committed. These activities are governed by a set of user-specified priorities for helitack use of bases and by a specified minimum load. The minimum load restriction becomes invalid if all bases of a given priority lack the specified force level. More than one helicopter can be dispatched to a fire using preplanned area dispatch, or by specifying a maximum number of helicopters to be used on one fire. FOCUS does not impose any density- altitude limitations on helicopter load capabilities.

The user may specify that helicopters also be assigned to lift road vehicle-transported crews from the road to the fire when certain conditions are met. These are:

- Walk time from road to fire exceeds 15 minutes.
- The helicopter will not wait more than 30 minutes for the crew to arrive. The actual limiting wait time for the helicopter varies from 1 minute if walk time is just over 15 minutes to 30 minutes if walk time is 60 minutes or more.
- The crew would not get to the fire sooner by walking.

Helicopters are assumed to land near the fire on prepared and maintained landing spots or on natural landing areas as specified. A combination mode may be chosen in which a prepared landing spot is used if located within a specified distance from the fire, otherwise a natural landing spot is used. A fixed average walk distance from natural landing spots to fires is specified by the user.

Dual mode aircraft, which may or may not be rotating wing aircraft, use the data coding and program logic for helicopters. The defining property of a dual mode unit is that it delivers men close to a fire on a first trip, then switches to an air tanker operation. A walk distance from landing to fire which is different from that for other helicopter-delivered crews may be specified. The intent here is to model water-based fixed-wing aircraft as well as dual mode helicopter operations. The fixed-wing planes land on water bodies to deliver crews, then begin a water scooping and dropping operation. More will be said about dual mode units in the discussion of air tankers below.

Smokejumpers—Decisions about smokejumper use and crew size are made for each fire by the FOCUS dispatching logic. Jumpers are dispatched from bases or from airborne planes with uncommitted jumpers aboard. The locations and load status for all smokejumper transports are determined at the time of the fire, and the total time for placing the specified number of jumpers at the fire is minimized. This objective may require immediate dispatch of one or more plane loads from one or more bases, multiple trips by one aircraft, the use of partial loads already in the air, or some combination of these modes. Smokejumper delivery times are calculated from user-supplied load times and cruise speeds for aircraft, assuming straight point-to-point distances. Total times also include user's streamer plus drop times along with an additional time per man for assembling the crew and equipment on the ground. Streamer time refers to the practice of dropping and observing ribbon streamers for estimating the wind drift of parachutes.

Air Tankers—Three operational modes are available to an air tanker. The first mode limits an air tanker to operation from its home base. The second mode allows initial dispatch from home base; but in multiple fire situations, refills and subsequent dispatches will be from bases which can handle the aircraft and which are closest to the fires. The third mode provides for helicopters or water scooping tankers to refill at a source close to the fire. Dual mode aircraft operate as air tankers in the local refill mode. When assigning aircraft to this mode, the user may partition his planning unit into four sectors and specify an average distance from fires to local refill sources in each sector. An air tanker's complement of full tanks can be expended on a single fire; or, in a multiple fire situation and depending on need, the payload can be divided among two or more fires.

Sequence Generation—Using the parameters and operational modes for ground and air attack, a sequence of possible unit arrivals, ordered in time without regard to production rate, is generated for each fire. Unit types, or line building resources, are not included in this list if they are excluded from the fire area by the fire occurrence data. The program truncates the list, that is, sequence generation is stopped for each type of line building resource, when line production capability is sufficient to allow easy containment of a fire. The dispatching portion of the program (see *sec. 3.3*) decides what part of the potential arrival sequence list is actually made available for fire suppression calculations.

3.2.2 Program Assumptions

Ground Units—The parameters which define ground units, associated limitations on size and numbers, and other pertinent requirements are defined in the *FOCUS User Manual* (USDA Forest Service 1977c, p. C-1). No attempt is made to duplicate that information here.

An important ground unit consideration is staffing. The FOCUS program has the capability to vary the available units and total personnel on a daily basis, depending on the fire danger situation for a given day. This capability simulates the use of "manning and specific action guides" (USDA Forest Service 1972), based on predicted fire weather. In actual operations, work force changes are sometimes instituted for reasons not directly related to daily weather, such as a reduced work force at night, increased personnel on weekends, or movement of crews in response to lightning storm conditions. These and similar staffing changes are handled in the FOCUS program by up to three user-defined special conditions for each unit. On the individual fire occurrence records, any one or combination of these conditions can be started, or stopped if previously in effect. Crews and equipment are placed on or off duty at the time of each fire as determined by an appropriate set of data. Movements between bases are accomplished by taking units or workers "off" one base and putting them "on" another.

Another staffing capability in FOCUS allows users to specify two sequential days off during the week for those units which are on a 5-day workweek.

One limitation occurs when a special work force condition is initiated. In this event, work force levels for all ground units are reset to normal prior to initiating the special work force adjustments. This situation could cause an unrealistic use of units if, for example, the special work force mode were initiated within a multiple fire sequence. Units which should remain committed to specific fires would suddenly be on base and available for dispatch. This program limitation circumvents the difficult simulation and programming problems which would occur when a previously committed unit suddenly goes off duty or has its work force level changed.

Travel times from ground bases to fires are calculated using a set of user-supplied road network data. The computer program determines the routes which give the earliest arrival times. The road data include node locations (such as intersections and resource bases), two direction travel times between nodes for three vehicle classes, roadside barrier flags to stop units from leaving a road segment on either or both sides, and designations of segments as vehicle roads or as trails for foot travel only. Node elevations above sea level are optional data.

Road configurations are approximated by straight-line segments from node-to-node. Off-road travel is along straight-line paths to fire locations from either of the two road segments nearest in time to a fire. Off-road travel rates can be set by users for each vehicle class. A level-ground cross-country walking speed is also provided by users. If pumper use is excluded in a data option for a particular fire, off-road travel for crews is set at the foot travel rate.

The data may also provide for off-road travel barriers, such as rivers, cliffs, and other obstacles that impede travel. These barriers are optionally effective for any combination of the three vehicle levels and foot travel. If the straight-line path from any road segment to a fire location is interrupted by an off-road barrier segment, that path is not used in the travel time calculations.

It should be noted that off-road barriers are used for travel time calculations only and are not considered in fire spread calculations. Also, roadside barriers defined in the road network data affect only travel from the road segment to which they are attached and do not act like off-road barriers to prevent crossing from, for example, a nearby parallel road segment to a fire.

In some parts of the country, ground units routinely go from one fire to another without returning to their base. FOCUS cannot currently model such a "hot dispatch." As a partial solution for ground crews only, a user option for each simulated fire allows a zero return-to-base time thus eliminating the normal return travel time prior to the next dispatch.

Air Units—The data parameters which describe air units, including limitations on size and numbers, are described in detail in the *FOCUS User Manual* (USDA Forest Service 1977c, p. D-1).

The only FOCUS program restriction on the use of aircraft relates to darkness. Aircraft operating hours are assumed to be from 30 minutes before sunrise to 30 minutes after sunset. Since weather and terrain factors which might limit aircraft are neither required nor entered as data items, the burden rests on the user to restrict aircraft use (in the fire occurrence data) when such factors are involved.

Aircraft refueling and maintenance are not simulated. Aircraft availability is limited only by on-duty and off-duty dates, priority considerations, prior fire commitments, and darkness. Point-to-point air travel times are calculated using cruise speeds provided by the user for each air unit.

Helicopters and Helitack—Some crews can be transported by either ground vehicles or helicopters. The program assumes that that mode will be used which results in the quickest arrival at the fire. Ground transport could be used when helicopters are backlogged or are at a considerable distance from the crew and fire. When the helicopter option is chosen to deliver crews to the fire location, 1 minute is allowed as walking time in addition to the load and unload time which is part of the helicopter data.

Generating possible helitack arrivals is stopped when sufficient forces are in the arrival list for easy containment of the fire, considering both ground and helitack arrivals.

Smokejumpers—When a user option allows jumping on multiple fires with one plane load, transports are fully loaded when taking off to a fire which has occurred within 30 minutes of the previous fire, otherwise only sufficient jumpers for the one fire are loaded. The 30-minute criterion is used to indicate a possible multiple fire situation. Planes with men aboard, returning to base, may be diverted to any fire which occurs before arrival at base; 5 minutes are added to the flight time for changing course and finding the new fire.

A required number of smokejumpers is calculated for inclusion in the list of possible arrivals at a fire, assuming that no other type of line-building resource will be used. This number is subject to limitations by minimum and maximum values specified by users. The smallest transport plane that can carry the required number from the nearest base to the fire will be used. If required, more transports and additional bases may be used to obtain the calculated number of jumpers.

In the simulation, return-to-base times are the same as base-to-fire times, except for smokejumpers where the user provides a unique return-to-base time.

Air Tankers—Effective air tanker drop lengths are based on a table which is entered using a fuel loading index included in the data and a rate of fire spread index derived from the rate in the fire data. For multiple tank planes, a drop length per tank is calculated. The salvo size is then determined based on a nominal drop length of 3 chains. Tanks are combined if required until the effective drop length is 3 chains or more. Salvos are dropped using this number of tanks until no more are required on the fire or all the tanks are empty. Of course, the last salvo may use less tanks than the previous salvos.

The number of air tankers is based both on the dispatching decision rules and the fire rate of spread. Since air tankers are not considered to build and hold fireline except in association with ground crews, they are not considered in direct trade-off relationship with crews and equipment. The initial air tanker demand is anticipated by preplanned dispatch, then augmented when the actual ground dispatch and the fire rate-of-spread are determined. The number of air tankers is increased when the dispatch criteria for ground attack cannot be met or spread rate is high.

3.3 Dispatching Calculations

3.3.1 Planning Assumptions

The function of the dispatching portion of the FOCUS suppression module is to select a subset of possible resource arrivals at the fire for actual dispatch. Two dispatch modes are available and may be used exclusively or in combination: threat response dispatch (TRD) and preplanned area dispatch (PPAD). As implied, TRD is a response to the threat posed by an individual fire; whereas PPAD is a preplanned response which depends on the response area in which the fire is located and on the fire danger level. Follow-up dispatches in the PPAD mode are based on the TRD scheme. On individual fires, users may choose to use TRD, even though the PPAD mode is in effect. In PPAD, follow-up dispatches are delayed long enough to allow the first PPAD unit to arrive at the fire. A reconnaissance option may be chosen in the TRD mode in which dispatch of units after the first to arrive at the fire is delayed until the first unit arrives.

The TRD scheme attempts to match the total user-defined fireline production capability of dispatched units to a value several times the forward spread rate of the fire. This value is nominally 3.5 times the spread rate, but can have other optional values. The minimum value is either 2.0 times the spread rate or a value which assures a fireline production rate of at least 1 chain per hour. The program attempts to meet this criterion by the time the fire reaches a selected size, generally 1 to 5 acres. If line-production capability conditions cannot be met, the situation is judged as potentially dangerous and the attack is strengthened. An air tanker is dispatched, if available, and the production rate requirement is raised to 5.0 times the forward spread rate of the fire.

In the TRD mode, the user can select a fire danger level for automatic dispatch of an air tanker. If the fire danger in the fire vicinity is at or over the selected level, a single air tanker is dispatched. Additional air tankers are dispatched depending on the spread rate of the fire. Dispatch of additional air tankers is delayed until the first ground unit arrives at the fire.

When PPAD is used for initial attack, the TRD scheme is used as a back- up. If the preplanned area dispatch does not meet TRD criteria, these criteria are used to determine a follow-up dispatch. Calculating the dispatch to a fire is further refined in the attack calculation process. Units which have not arrived at the fire by the time the fire is contained are assumed never to have been sent and do not appear in the arrival list printout.

Dispatches to nonspreading fires (such as structures and vehicles) always use the PPAD scheme. A typical, or average, dispatch to each type of nonspreading fire is determined by the user and entered as PPAD data.

A priority scheme specified by the user determines the order in which various classes of resources will be dispatched. Resources are classified optionally by organizational or jurisdictional criteria. Class 1 ordinarily consists of primary attack forces within the planning unit. Class 2 may consist of planning unit resources such as work crews. Class 3 might consist of cooperators, including—for the Forest Service—State or county agencies. A maximum of 15 such classes can be defined. FOCUS users must establish a table which defines the normal dispatch priority or order for various types and classes of fire resources. The program first attempts to make a satisfactory dispatch using priority 1 units, then adds successive priority levels as needed. The data for each simulated fire occurrence has the capability to modify dispatch priorities for that particular fire. Agencies or resources other than planning unit initial attack forces can be specified as first priority for a given fire, while the regular initial attack forces can be relegated to a lower priority. This reordering of priorities could occur where fires are within an adjacent protection jurisdiction, such as a fire district within a National Forest.

3.3.2 Program Assumptions

Water exhaustion times for dispatched pumpers are calculated using a rate of 7.5 gallons of water per minute. When available, additional air tankers are dispatched from the simulated fire based on spread rate. One air tanker is added for spread rates over 10 chains per hour; two air tankers for spread rates over 20 chains per hour; and three air tankers if the forward spread rate is over 40 chains per hour.

3.4 Fire Attack Calculations

3.4.1 Planning Assumptions

The calculation of a hypothetical attack on a fire is based on the list of resource arrivals generated by the dispatching part of the FOCUS program. Three modes of attack can be used, as specified on the fire occurrence data for each fire: direct head attack, direct rear and flank attack, indirect or backfiring head attack.

The call for a direct head attack may be overridden by the program logic if sufficient forces are unavailable to ensure a safe head attack. Similarly, in an indirect head attack, the call may be overridden if the combination of forces and time available is not sufficient to construct a backfiring line which will hold the fire under escape size. In either case, the program converts to a direct rear attack mode.

For the direct rear attack, the method for assignments of forces to the fire flanks is an overall (not for individual fires) user option. The ratio of production rates on left and right flanks is the criterion specified. A simple programmed assignment schedule may also be called for. This much-used option attempts to equalize production rates on the two flanks up to a given level, then builds up on one flank to a strong attack, before again equalizing the flank production rates at a higher level. Of course, all of the assignment options are goals to try for, and they are governed by the availabilities of forces along with the necessity of making whole number assignments of personnel and equipment.

Fires are declared *escaped* by the program if user-specified escape parameters are exceeded for burned area or maximum time of engagement. For escaped fires, the program prints out the fire parameters, size at escape, time of escape, and length of fireline constructed. The total list of dispatched resources also is given.

If, in a multiple fire situation, resources are exhausted to the point where nothing is available to send to a fire, the fire is declared "no-dispatch" by the program and the fire parameters are printed out along with a calculation of when and how the fire would reach escape conditions if not attacked. This condition most often occurs either in evening fires when forces are exhausted by an afternoon lightning storm and air attack can no longer be made because of darkness, or in a heavy incendiary outbreak. If 20 consecutive "no-dispatch" fires occur, the program stops execution, assuming a data error exists.

Air tanker drops are assumed to perform a holding function only. Fire will spread around drops but not through them using the direct rear attack mode in the simulation. Drops must be backed up by fireline construction to be secure. The first drop on a fire is always made at the head. Subsequent drops may be tied in on the flanks if made before the fire spreads around the drop ends or made on new fire heads formed when the fire goes around the drops. A complex logic arrangement determines where drops subsequent to the first will be made, depending on previous drop geometry and crew locations and status.

When air tanker dispatch is called for on small, easily contained fires, a limited number of simulated drops may be made but are assumed to have no effect on final fire size. The effectiveness of such drops would be minimal, but they are included for costing purposes.

3.4.2 Program Assumptions

The basic free-spreading fire model used in FOCUS fire attack calculations is a growing ellipse with its origin at a focus (*fig. 9*). This ellipse is determined by three parameters—initial area, forward rate of spread, and length-to-width ratio or elliptical eccentricity. Values for these three parameters are entered as data for each fire in the simulated fire occurrence list. Rate of spread and length-to-width ratio are assumed constant throughout the fire attack calculations. Users are cautioned to consider these assumptions when setting the maximum, or escape, size for fires.

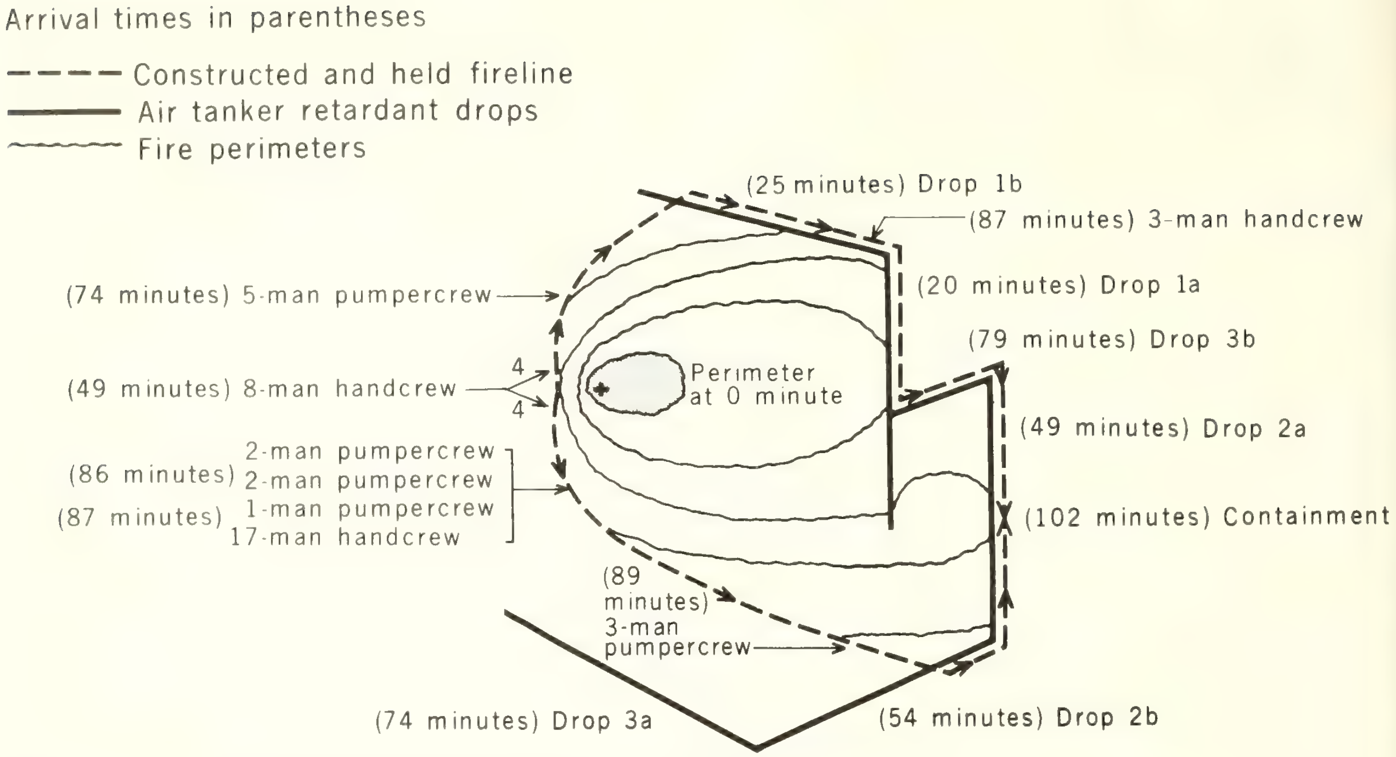

Arrival times in parentheses
Constructed and held fireline
Air tanker retardant drops
Fire perimeters
(25 minutes) Drop 1b
(87 minutes) 3-man handcrew
(74 minutes) 5-man pumpercrew
(20 minutes) Drop 1a
(79 minutes) Drop 3b
(49 minutes) 8-man handcrew
4
4
Perimeter at 0 minute
(49 minutes) Drop 2a
2-man pumpercrew
(86 minutes) 2-man pumpercrew
(87 minutes) 1-man pumpercrew
17-man handcrew
(102 minutes) Containment
(89 minutes) 3-man pumpercrew
(74 minutes) Drop 3a
(54 minutes) Drop 2b

Figure 10—The rates of fireline production change as reinforcements arrive.

The program performs two kinds of attack calculations—a table look-up procedure for easy fires, and more complex attack calculations when the fire cannot be controlled easily. First, an attempt is made to use a table look-up procedure for small, easy fires (Bratten 1978). The look-up tables give the size and time at containment under assumptions of equal assignments to the two fire flanks and no air tanker effectiveness. All line-building resources which arrive within 15 minutes of the first units are used. The fireline construction rate is accumulated for these first arrivals. An average arrival time is calculated by weighting the individual arrival times by the production rates. Production rates for pumpers in the arrival list are weighted by considering their exhaustion times from the arrival list and assuming that the engagement time on the fire is 1 hour. Average production rates are calculated by using production rates with water until exhaustion, and hand crew rates for the remainder of the hour.

The look-up tables are entered using the initial fire area from the fire occurrence data, the average arrival time, and the total production rate. The available production rate is assumed to be split equally between the two fire flanks. If the result is containment at less than 10 acres in less than 2 hours, the size and time are accepted and no further attack calculations are performed.

If the fire cannot be controlled within these limits, the program goes into one of the three attack modes discussed in *section 3.4.1*. The results from part of the table look-up calculations are used to check and perhaps modify the user's designation of head or rear attack mode for each fire. If head attack is specified, the initial production rate for the table look-up calculations must exceed a minimum value. Otherwise, the attack designation is changed to rear. The criterion for head attack is that the ratio of production rate to forward spread rate must exceed (3 + 6 V) where V is the forward spread rate in chains per minute specified in the fire data. This criterion defines a boundary between easy and difficult containment by direct head attack. By this criterion, difficult head attack is assumed hazardous and should not be attempted. (This discussion does not apply to indirect head attack.)

In direct attack calculations, fireline production rates are integrated along the perimeter of the growing fire ellipse with changes in these rates as new arrivals are assigned (*fig. 10*). Fireline production rates may decrease when pumper crews run out of water, at which time they may begin work with handtools, depending on data input. When pumpers are refilled from either local sources or nurse tankers, production rates return to the higher values. When nurse tankers arrive at a fire, the water supply is assumed to be shared equally between all pumper units on the fire.

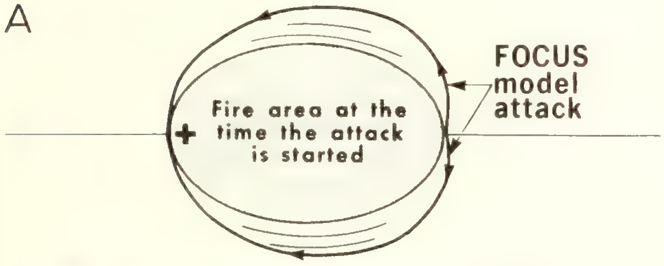
Reassignment of crews may occur as new resources arrive in an attempt to reach or maintain assignment criteria. In extended attack calculations, units are assigned to the two flanks of the fire as they arrive, attempting to give equal production rates for head attacks, or to meet user-specified criteria for rear attacks.

Air tanker drops are treated as fire barriers in FOCUS. Fire will not spread through them; however, to be completely effective, crews must tie the fireline to the drops and complete a backup line behind them before the fire spreads around them.

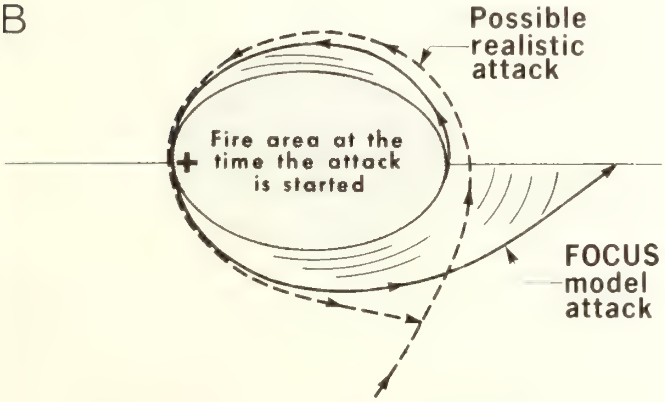
For direct head attack, retardant drops from air tankers in the arrival list do not affect the calculations, though they are retained in the list for printout and costing. It is assumed that such drops would be used to aid crews in line work, and would have negligible impact on calculated fire area.

The geometry of direct head attack by two high production rate units is similar to the tactics that normally would be employed by actual units. Each direct head attack unit starts from the forward end of the long ellipse axis and produces a fireline until they meet toward the rear of the fire (*fig. 11A*). Note that in this case the forward spread of the fire is entirely stopped.

When the fire is attacked by only one crew, the geometry is somewhat different (*fig. 11B*). In this case the unit starts at the head and circles around behind the fire. The fire continues to spread in the unattacked forward quarter and the control line must be built until it intercepts the long axis of the fire ellipse at the forward edge of the fire. At this point FOCUS departs somewhat from reality since the line is not built back to the starting point; however, at least as much control line is constructed as likely would have occurred in the "real world."



By two high production rate units


B
Possible realistic attack
Fire area at the time the attack is started
FOCUS model attack

By single high production rate unit

Figure 11—Direct head attack as modeled by FOCUS for two crews *(A)* and a single crew *(B)*.

With the exception of fires starting along roadsides, FOCUS does not consider natural or manmade barriers to fire spread other than the control line put in during the fire. Although the occurrence of natural forms such as rivers and cliffs may act as barriers to foot and off-road vehicle travel, they do not influence fire size or shape. Roadside fires are the exception and always spread away from or along the road but do not cross it.

In direct rear attack calculations, the first drop is made across the head of the fire, assuming that line construction has not already stopped the fire head (*fig. 10*). Subsequent drops are made using a logic scheme based on the status of crews working on the two flanks of the fire and the events which have occurred since the previous drop. In general, successive drops are made to tie in with drops already made. The drops are oriented to maximize the chances that crews will be able to tie control line to the drops before the drops are bypassed by the fire.

Only in direct rear attack calculations are retardant drops treated as impenetrable fire barriers that can be bypassed only by fire spreading around the ends. Retardant drops associated with an indirect head attack are assumed to be penetrated after a set time.

Indirect head attack calculations assume that backfiring lines are constructed ahead of the fire. The user can specify the number of parallel, adjacent lines judged necessary. This set of line is placed so that it will be completed by a specified time preceding arrival of the fire head. The production units then begin line construction on one or both flanks to complete the line around the fire. The same basic elliptical fire growth model is used for both indirect head attack and direct attack (*fig. 12*). The tactic simulates a section of fireline ahead of the fire which may or may not be fired out or backfired. Line is then constructed from the ends of the backfire line on one or both flanks and tied in for direct attack at the widest part of the fire. Containment is achieved either by tie-in of the two crews, or by a single crew encircling the fire after constructing the line across the head (*fig. 12A and B*).

The geometry of the attack ensures that the attack on at least one flank will be completed. If the attack on the other flank is too weak, any forces tentatively assigned to it are shifted to the strong flank. A one-way encirclement of the fire is attempted back along the strong flank, then forward on the weak flank to tie in with the backfire line on that end (*fig. 12B*).

Another possibility considers that forces will arrive on the weak flank after the fire has hit the backfire line but before it goes around the end. If these forces are strong enough, a direct flank attack is mounted from the backfire line; otherwise, the forces are added to strengthen the attack from the strong side (*fig. 12C*).

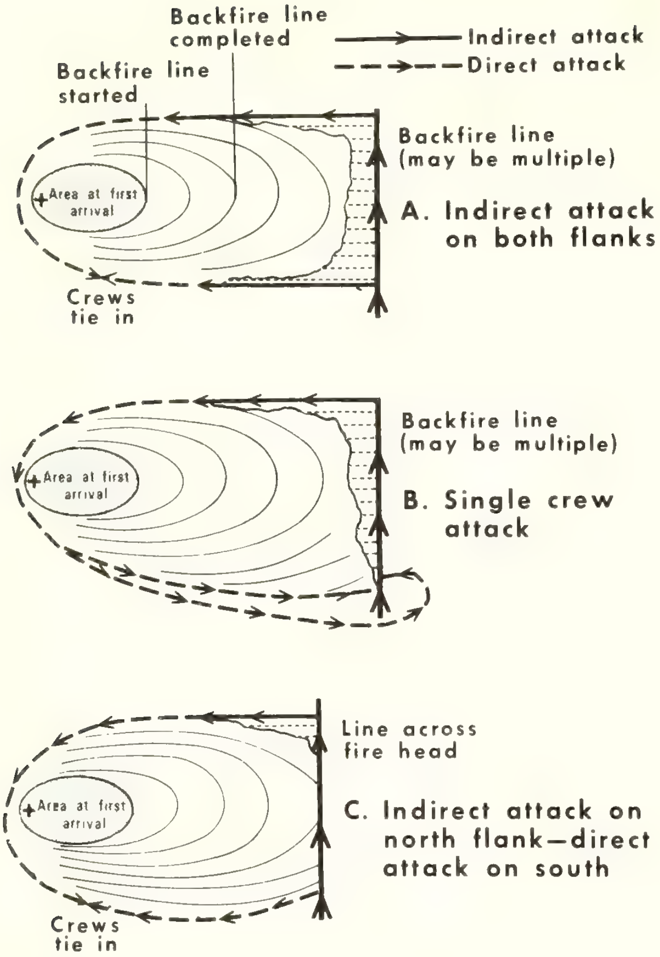


Figure 12—Examples of simulated backfire or indirect head attacks.

Attacks are governed by a set of user data which specifies three attack parameters based on fire rate of spread, fuel type, experience and custom. The parameters are:

- Time from backfiring line completion to arrival at the line of the fire head.
- Ratio of backfiring line length to width of fire at the time of backfiring line completion.
- Multiplicity of backfiring lines, that is, the number of parallel single lines constructed to form the backfiring line.

A maximum of three air tanker retardant drops, made before backfiring line completion, can be used to slow the forward spread, allowing the backfiring line to move in and decrease the final fire size.

The retardant drops are assumed to hold the fire for a maximum of 15 minutes; the fire may spread around the ends before that time. After 15 minutes, the fire can spread through the drop (*fig. 13*).

3.5 Mop-up Calculations

3.5.1 Planning Assumptions

Once a simulated fire is declared contained or escaped in the fire attack calculations, some units are retained on the fire, that is, made unavailable for dispatch, in the mop-up part of the program. Program users provide data giving time spent on mop-up and number of units required, depending on unit type, fire size, and fuel type. The user also indicates a priority order for retaining units on mop-up, based on the resource classes (see *sec. 3.3.*) Those user-supplied data are used for contained fires only. For escaped fires, an internal set of rules applies.

Some experience-based but more or less arbitrary assumptions are made about escaped fires and the time that units will be committed to such fires, since the time of control and the time for mop-up are indeterminate in the program. All primary attack forces will be available for dispatch at 0800 on the morning after the day of the fire. These same forces will be available at noon when committed to fires occurring between midnight and 0800. Secondary forces are held on the fire for 24 hours. Cooperators are held for 8 hours then released, unless they are helitack units which are released 2 hours after escape time. Primary initial attack forces are interpreted to be resource Class 1, secondary forces are Class 2, and cooperators are all higher classes in the program.

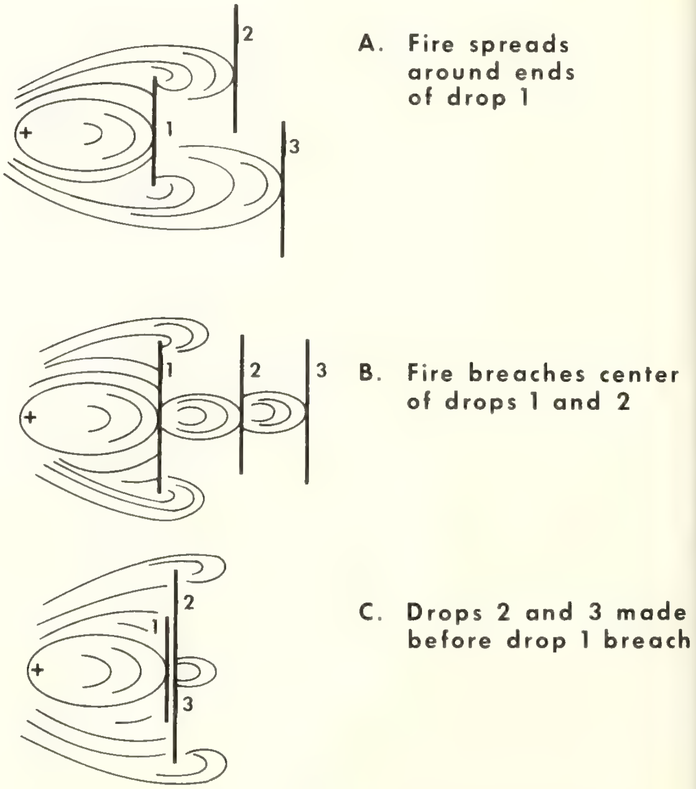

2
1
3
A. Fire spreads around ends of drop 1
1
2
3
B. Fire breaches center of drops 1 and 2
2
1
3
C. Drops 2 and 3 made before drop 1 breach

Figure 13—Examples of air tanker drop geometry in backfire attack.

These arbitrary rules obviously would not apply well to campaign fires extending over 2 or more days, and might be overly conservative for fires which are only slightly over escape size—typically 100 acres. The intent is to reflect the impact of large fires on initial attack capabilities without being too severe.

3.5.2 Program Assumptions

Data for contained fires consider three kinds of mop-up resources: hand crews, pumper crews, and bulldozers. Often, these types are not all present on a fire, so other resources must substitute. Strict substitution rules are not adhered to between these resource types, but the presence of one or more bulldozer for mop-up is assumed to reduce the labor requirement by 30 percent. The requirement for hand crew forces is considered first. Where this requirement cannot be filled, any pumper crew is assumed to be "worth" five hand crew members.

When mop-up requirements for hand crews require less than the smallest crew size on the fire, the crew will be split. The part of the crew not needed will be returned to base immediately, if more than one person.

3.6 Suppression Module Output

3.6.1 Planning Assumptions

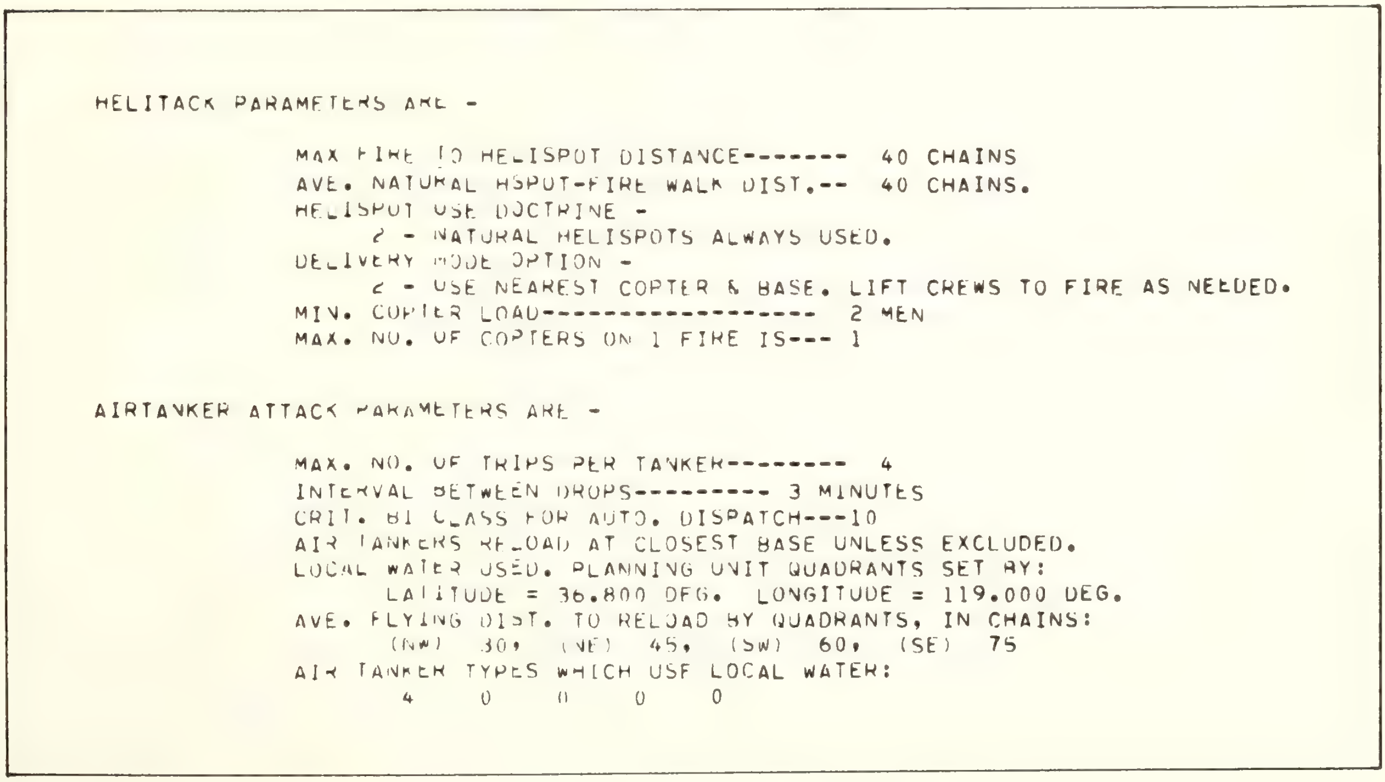
Examples of printed output were given in *section 3*. Additional printouts available in production runs include the run set-up data and a complete list of the base plan resource unit and base data along with any changes made for a particular alternative run. These printouts are displayed in easily read formats. One example is the run set-up parameters for helitack and air tanker attack (*fig. 14*). Similarly, data printout examples are shown for helitack bases and helicopters (*fig. 15*).

The FOCUS cost module calculates and summarizes the costs of suppression operations of a fire organization. Part of the costs are on-the-fire suppression costs for labor and equipment. The suppression module must supply the computer-based information needed by the cost module to calculate suppression costs on the simulated fires. Such a file is generated on demand by the suppression module.

Special diagnostic printouts from the suppression module provide a method of analyzing the complete operation of the module (*sec. 3*). These printouts are used principally by program maintenance technicians, but are available to knowledgeable users to assess the program's handling of one or a few simulated fires. This type of printout can be quite extensive and impractical for a large number of simulated fires.

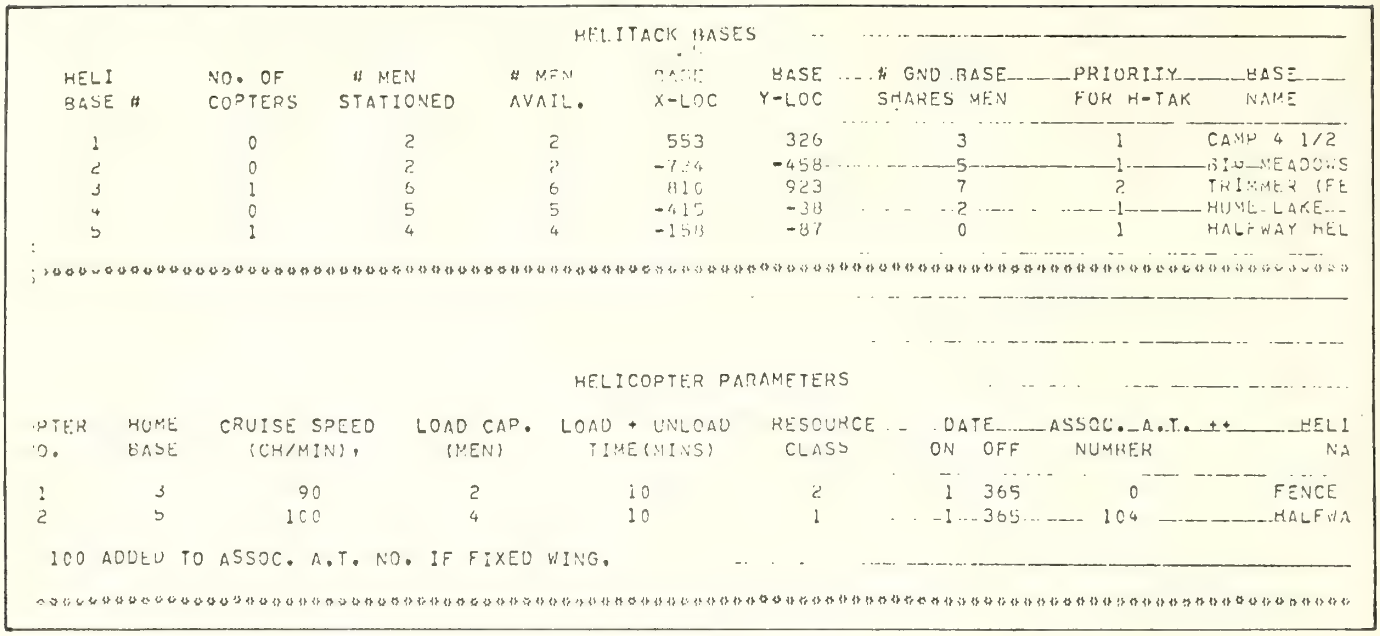
3.6.2 Program Assumptions

The quantities which can be printed out or written in the cost module file and the formats used are internal program features. Users can choose only whether to use these capabilities.



```
HELITACK PARAMETERS ARE -

            MAX FIRE TO HELISPOT DISTANCE-------  40 CHAINS
            AVE. NATURAL HSPOT-FIRE WALK DIST.--  40 CHAINS.
            HELISPOT USE DOCTRINE -
                2 - NATURAL HELISPOTS ALWAYS USED.
            DELIVERY MODE OPTION -
                2 - USE NEAREST COPTER & BASE. LIFT CREWS TO FIRE AS NEEDED.
            MIN. COPTER LOAD------------------  2 MEN
            MAX. NO. OF COPTERS ON 1 FIRE IS--- 1


AIRTANKER ATTACK PARAMETERS ARE -

            MAX. NO. OF TRIPS PER TANKER--------  4
            INTERVAL BETWEEN DROPS--------- 3 MINUTES
            CRIT. BI CLASS FOR AUTO. DISPATCH---10
            AIR TANKERS RELOAD AT CLOSEST BASE UNLESS EXCLUDED.
            LOCAL WATER USED. PLANNING UNIT QUADRANTS SET BY:
                 LATITUDE = 36.800 DEG.  LONGITUDE = 119.000 DEG.
            AVE. FLYING DIST. TO RELOAD BY QUADRANTS, IN CHAINS:
                 (NW)  30,  (NE)  45,  (SW)  60,  (SE)  75
            AIR TANKER TYPES WHICH USE LOCAL WATER:
                 4    0    0    0    0
```

Figure 14—Example of suppression module output: run set-up parameters for an air attack.



```
                                               HELITACK BASES

  HELI        NO. OF      # MEN        # MEN        BASE       BASE    # GND BASE    PRIORITY      BASE
  BASE #      COPTERS   STATIONED      AVAIL.       X-LOC      Y-LOC   SHARES MEN    FOR H-TAK     NAME

    1           0           2            2           553        326        3            1        CAMP 4 1/2
    2           0           2            2          -734       -458        5            1        BIG MEADOWS
    3           1           6            6           810        923        7            2        TRIMMER (FE
    4           0           5            5          -415        -38        2            1        HUME LAKE
    5           1           4            4          -158        -87        0            1        HALFWAY HEL

**********************************************************************************************************


                                               HELICOPTER PARAMETERS

PTER   HOME    CRUISE SPEED   LOAD CAP.   LOAD + UNLOAD   RESOURCE    DATE     ASSOC. A.T. ++        HELI
O.     BASE     (CH/MIN),      (MEN)       TIME(MINS)      CLASS     ON  OFF     NUMBER               NA

1       3         90             2            10             2        1  365        0                FENCE
2       5         100            4            10             1        1  365       104               HALFWA

 100 ADDED TO ASSOC. A.T. NO. IF FIXED WING.

**********************************************************************************************************
```

Figure 15—Example of suppression module output: bases and aircraft.

4. COST MODULE

The cost module computes the suppression costs and damages associated with the fire plan and fire workload. Dollar rates are applied to the hourly total of labor and equipment from the suppression module, resulting in total costs. Proper dollar equivalents are also applied to acres burned by damage potential classes which are derived from the suppression module, resulting in total damages. The cost module is an aid to determine total costs and damages whereby alternative plans may be compared. The program is not intended as a precise accounting system for individuals and equipment. Many cost items are too detailed to be simulated and must be entered as estimated averages. The dollar cost and damage summaries should be used to rank the cost elements rather than to achieve a precise dollar difference between plans. Further FOCUS use and analysis of results are needed to determine at what point differences between plans constitute an amount of significance to management.

The cost module consists of two programs: SMOKEY I and SMOKEY II. SMOKEY I requires input which is closely related to the suppression module input. SMOKEY I provides summaries and error checking printouts and stores base and unit costing data. SMOKEY II calculates suppression costs from the combined input of the base and unit costing data of SMOKEY I and the fire suppression history from the suppression module.

The objective of the cost module is to assess dollar values of costs and losses for each initial attack alternative. Costs are separated as fixed or variable (*fig. 16*). Suppression costs represent only the values of equipment and people actually used in on-fire activity (*fig. 17*). Such values may not be comparable to the real world fire budgeting which, under certain circumstances, often permits several Federal agencies and many States to allocate so-called emergency firefighting funds to presuppression activities.

4.1 Assumptions and Limitations

4.1.1 Planning Assumptions

The cost module computes functional summaries based on the suppression module data set of suppression force use and the cost module data set of rates. This modeling assumes the validity and sensitivity of the suppression module estimates, the ability to express user accounting methods to cost labor and equipment in a small number of present options in the cost module, and the deterministic calculation of all costs from these suppression force uses and rates.

Because cost module input is derived from suppression module output, the cost module shares all the appropriate assumptions.

The accuracy of cost module estimates must never be confused with that of accounting printouts. The precision of the required inputs and computerized summaries, which implies more accuracy than is justified, could be misleading to the decisionmaker. FOCUS is a planning tool whose dollar totals are for ranking purposes or paired comparisons only. The cost module is designed to test alternative plans, not to budget differences within or between regions. The cost module is intended to provide information for fire management decisionmaking.

```
                              COST   SUMMARY
                               SEASON 1980

INITIAL ATTACK                          1702538
PREVENTION                                23492
DETECTION                                 43011
OTHER(FIRE)                                6053
OTHER(NONFIRE)                              989

SUBTOTAL FIXED COSTS                                     1776087
----------------------------------------------------------------

UNUSED CONTRACTS                         204738
NORMAL MANNING (NON SUPR)               1033219
SUPPRESSION                                   0
SUBTOTAL VARIABLE COSTS                                  1237957
----------------------------------------------------------------

POTENTIAL DAMAGE                                               0
----------------------------------------------------------------

COSTS PLUS POT. DAMAGE                                                3014044
-----------------------------------------------------------------------------

* CONSULT PAGE 10-40 IN FOCUS USER MANUAL FOR DEFINITION OF COST TERMS
```

Figure 16—Example of cost module output: summary of fixed and variable costs.

```
                                                                                   TYPE--GROUND CREWS AND PLOWS / BULLDOZER
                                         FOR SEASON 1970
                       ------------------------------------------------------
 B U NAME                 UNUSED         NORMAL      SUPPRESSION    # OF     MILES      MAN HR    # OF     # OF       # OF RET
                       CONTRACT MIN     MANNING         COST        FIRES   TRAVELED    SUPR     TRIPS   MEN SENT     LOADS
-- - ----              ------------     -------      -----------    -----   --------    ------   -----   --------   --------

 1 1 STOCKTON ENGINE        0.          24705.00          .00         0.         .0        .0
 2 1 MORMON ENGINE          0.          24705.00          .00         0.         .0        .0
 2 2 MORMON ROCK FPT        0.           5307.00          .00         0.         .0        .0
 2 3 MORMON TRACTOR         0.           5845.00          .00         0.         .0        .0
 2 4 MORMON NURSE           0.           4843.00          .00         0.         .0        .0
 3 1 LYTLE CR ENGINE        0.          48756.09      2560.31        17.      881.0     279.8
 3 2 LYTLE CR FPT           0.          21040.47       646.87        12.      672.0      67.7
 3 3 LYTLE CR IRC           0.          11680.00          .00         0.         .0        .0
 4 1 SAN SEVAINE ENG        0.          24705.00          .00         0.         .0        .0
 4 2 SAN SEVAINE HTK        0.          30856.00          .00         0.         .0        .0
 5 1 DAY CANYON ENG         0.          24705.00          .00         0.         .0        .0
 5 2 DAY CANYON FPT         0.          10614.00          .00         0.         .0        .0
 6 1 SYCAMORE ENG           0.          24705.00          .00         0.         .0        .0
 7 1 COTTONWOOD ENG         0.          24705.00          .00         0.         .0        .0
 7 2 COTTONWOOD FPT         0.          10614.00          .00         0.         .0        .0
 7 3 COTTONWOOD NURS        0.           4843.00          .00         0.         .0        .0
 8 1 WATERMAN ENG           0.          24705.00          .00         0.         .0        .0
 8 2 WATERMAN FPT           0.          21036.36       860.23        13.     1260.0      86.5
 9 1 DEVILS CYN ENG         0.          24705.00          .00         0.         .0        .0
 9 2 DEVILS CYN FPT         0.           5307.00          .00         0.         .0        .0
10 1 ROCK CAMP ENG          0.          24705.00          .00         0.         .0        .0
10 2 ROCK CAMP FPT          0.          10614.00          .00         0.         .0        .0
11 1 SKYFOREST ENG          0.          48893.34      1583.53        14.      496.0     209.6
11 2 SKYFOREST FPT          0.          21134.60       129.95         3.      178.5      14.8
12 1 CITY CREEK ENG         0.          24705.00          .00         0.         .0        .0
12 2 CITY CREEK FPT         0.          10614.00          .00         0.         .0        .0
13 1 CRAB FLATS ENG         0.          24705.00          .00         0.         .0        .0
14 1 DEER LICK ENG          0.          24705.00          .00         0.         .0        .0
14 2 DEER LICK FPT          0.          21040.95       772.28        11.     1186.5      75.8
14 3 DEERLICK TRACT         0.           5845.00          .00         0.         .0        .0
15 1 BIG PINE FL ENG        0.          24705.00          .00         0.         .0        .0
15 2 BIG PINE FL NUR        0.           4843.00          .00         0.         .0        .0
15 3 BIG PINE FL FPT        0.          10614.00          .00         0.         .0        .0
16 1 SANTA ANA ENG          0.          24705.00          .00         0.         .0        .0
17 1 FAWNSKIN ENG           0.          49080.37      1632.44         9.      655.0     165.3
17 2 FAWNSKIN FPT           0.          10585.00        23.49         1.       48.0       1.4
17 3 FAWNSKIN HTSHOT        0.          96860.00          .00         0.         .0        .0
18 1 CONVERSE ENG           0.          24705.00          .00         0.         .0        .0
19 1 HEART BAR ENG          0.          24705.00          .00         0.         .0        .0
19 2 HEART BAR FPT          0.           5307.00          .00         0.         .0        .0
20 1 CAMP ANGELUS EN        0.          24705.00          .00         0.         .0        .0
20 2 BARTON FLTS FPT        0.          10614.00          .00         0.         .0        .0
20 4 CAMP ANG TRACT         0.          12775.00          .00         0.         .0        .0
20 5 CAMP ANG NURSE         0.           4843.00          .00         0.         .0        .0
20 6 CAMP ANG HELISH        0.          67802.00          .00         0.         .0        .0
```

Figure 17—Example of cost module output: summary of base and unit costs.

Errors can have a cumulative or biasing effect. For example, if amortization of replacement costs and maintenance are omitted from all owned equipment, the output will be biased against contracted equipment, even though such items are obviously included in corresponding guarantees and rates. Therefore, contracted equipment will appear less cost-effective than owned equipment.

4.1.2 Program Assumptions

The cost module operates under the set of system assumptions and limitations discussed in *section 4.1*. A few of the parameters in the cost module are limited because of the confining amount of real world fire costs which the program could model, and the lack of needed cost data in current Forest Service inputs. Therefore, the cost module inputs are assumed to be averages and estimates. The user may define the values for the seven classes of damage potential. These values are applied to the suppression results to provide a measurement of fire damages. The output should be used only to rank plans, not to reflect dollar values, since no current method exists to base these values on sound economical studies.

The cost module logic is relatively simple, compared to the suppression module. Basically, the suppression module simulates a fire season; the cost module accounts for the results. Therefore, the cost module assumptions discussed below are few.

The damage values for the seven classes may be either positive or negative which allows for a fire that may give a benefit versus a loss. In this case, a negative damage figure is displayed for the fire and subtracted from the seasonal totals. Escape and no-dispatch fires are not accounted for in the cost module, therefore they must be accounted for in the gaming process.

Manning charges are computed differently depending on the pattern and type of staffing. Normal staffing charges (crews not on fire status) are computed as a minimum crew cost plus any additional staffing costs that occur. The minimum crew cost provides a method of lumping different employee grades or pay scales into one figure. Any individuals added to the minimum crew are assumed to be firefighters at a standard pay rate. For example, the first nonzero number in a staffing pattern is assumed to be the minimum crew size (*table 2*). For purposes here, the minimum crew size is assumed to be three persons. If the staffing level for a particular day happens to be very high, then two extra persons are accounted for in the minimum crew cost. However, if the staffing pattern decreases as the staffing level increases (*table 2*), the normal staffing charges are omitted to prevent any negative costs. This change might occur if crew members were shifted to more critical locations as fire danger increases.

Table 2—*Patterns for increasing or decreasing staffing, by staffing levels*

Staffing	Low	Medium	High	Very High	Extreme
	Crew Size				
Increasing	0	3	3	5	5
Decreasing	5	5	3	3	3

The staffing charges for personnel on fire status are computed as normal for an increasing staffing pattern. However, if a decreasing staffing pattern occurs, the number of personnel dispatched are multiplied by the standard cost for an extra person. Therefore, the charge for this particular crew may not be adequately represented because the total personnel on the crew are assumed to be at the same pay scale.

The suppression module has the capability to modify staffing under special conditions, as defined by the user. The cost module adequately accounts for labor under special staffing conditions only for fire status. The cost module does not account for crews on special staffing if they are not on a fire.

Overtime charges are at the rate of time-and-a-half for fire staffing. Overtime is assumed to include the hours after 6:00 p.m. and before 9:00 a.m. The overtime rate is not charged if a crew works on its regular day off. Normal time in the cost module is 7 days a week from 9:00 a.m. to 6:00 p.m. Anything outside the above parameters will be charged to overtime if the overtime option was selected at the beginning of a run.

Crews receive hazard pay only if the appropriate option has been selected, if the crew is currently paid a normal staffing charge, and only if the crews are on fire assignments. The rate is time-and-one-quarter from 9:00 a.m., regardless of the time of the fire. For example, if a crew goes to a fire at 5:00 p.m. and returns home at 10:00 p.m., it will be paid the normal rate from 9:00 a.m. to 5:00 p.m.; hazard pay is accrued from 9:00 a.m. at a rate of one-quarter the normal salary until they return home. Overtime is paid from 6:00 p.m. to 10:00 p.m.

4.2 Input Data Requirements

The SMOKEY I program and related input forms are quite detailed. However, to simplify, the cost input for any unit may be lumped into one or a few cost entries if this level of accuracy is sufficient to produce satisfactory output. The accuracy of the cost input data is related to the differences in the alternative plans tested and the limitations of the program. Per diem costs, lost tools, and related items must be accounted for by averages for salaries and recurring costs. Similarly, operating cost figures such as maintenance of a guard station should be averages rather than a specific year's cost. For example, if the guard station costs are known to have been $50 and $350 for the past 2 years, the average $200 per year is a more usable entry for simulation purposes than either $50 or $350. The cost data should be entered as averages in current dollars.

Damage figures are inherently more problematic than costs and often dominate an economic analysis. Certain fires are viewed as beneficial and therefore their effects are incorrectly calculated by present value classes; at the same time, other fire damages may be underestimated. The SMOKEY programs will accept any resource damage potential classes entered on the suppression module fire data cards and any dollar values (including negative) for the damage values. A maximum of seven damage potential classes and associated dollar values are the only limitations.

Some contention prevails that cost-plus-loss analysis does not provide adequate information for management decisions, in which case the opportunity exists to apply one's ingenuity. For example, hour control standards could be substituted for damage potential class on the fire data cards. The suppression module can print out acreages by classes or hour control standards. Then, within the group of alternate plans that meet some set of hour control criteria, costs may be compared to achieve improved management decisions.

4.3 Output Descriptions

The reliability of the output is related to the validity of the program logic and the reliability of the input data. Judgment in using this management tool is developed along wih experience in using FOCUS to evaluate a variety of alternatives with familiar local data.

SMOKEY II, unlike its counterpart SMOKEY I, does not attempt to scan data for errors or insist that errors be corrected before the program runs. Instead, the program considers the possibility that the interface between the suppression and cost modules is not perfect. Rather than demand that data be corrected, the program simply prints a message and assigns a default value. User response to these errors is usually not necessary, therefore their messages are embedded within the listing where detected:

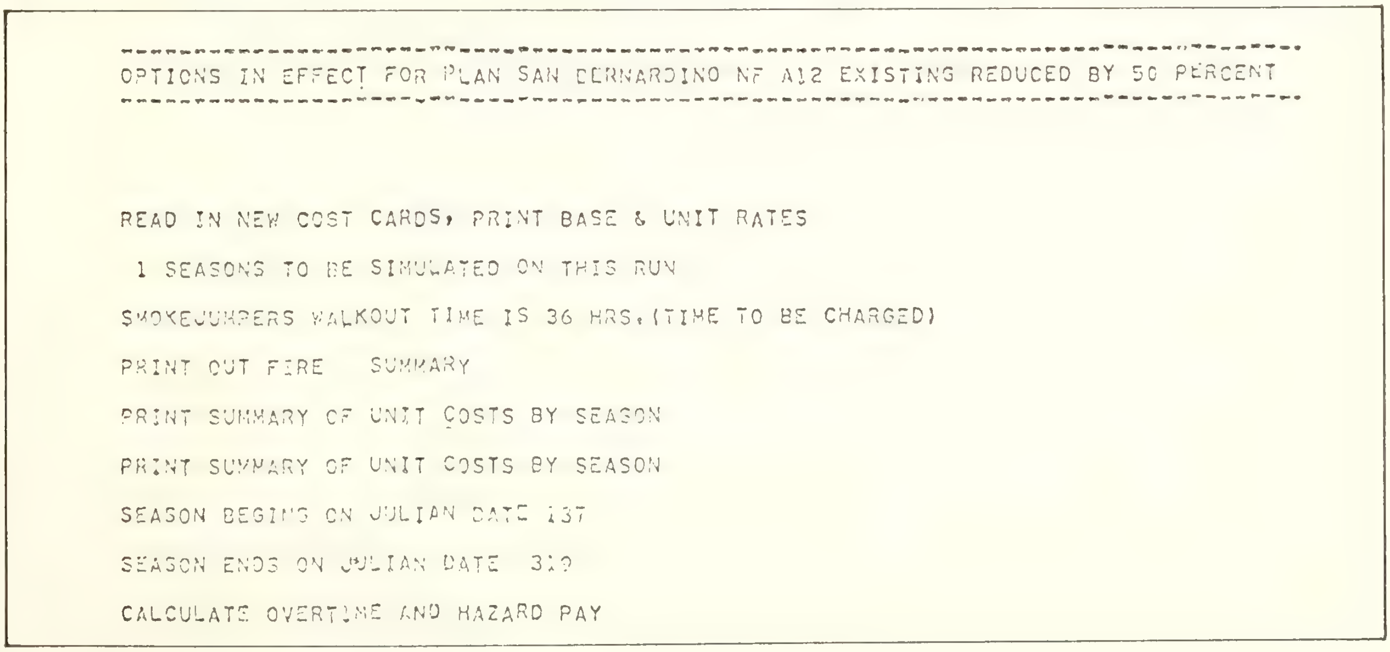
4.3.1 Output Options

In SMOKEY II, users can make optional choices of eight parameters controlling program operation, including printouts. Default values are used for these options when the user does not specify alternatives. The sample computer printout table for the SMOKEY II options (*fig. 18*) lists the default interpretations. Other user choices would be similarly listed.

Printed outputs from SMOKEY I include the base (*fig. 19*) and unit (*fig. 20*) costs which users provide, along with the totals for these costs (*fig. 21*). Simulation results are not included in these costs, so they have no relevance for judging the merits of plans or alternatives. These are provided by SMOKEY II.

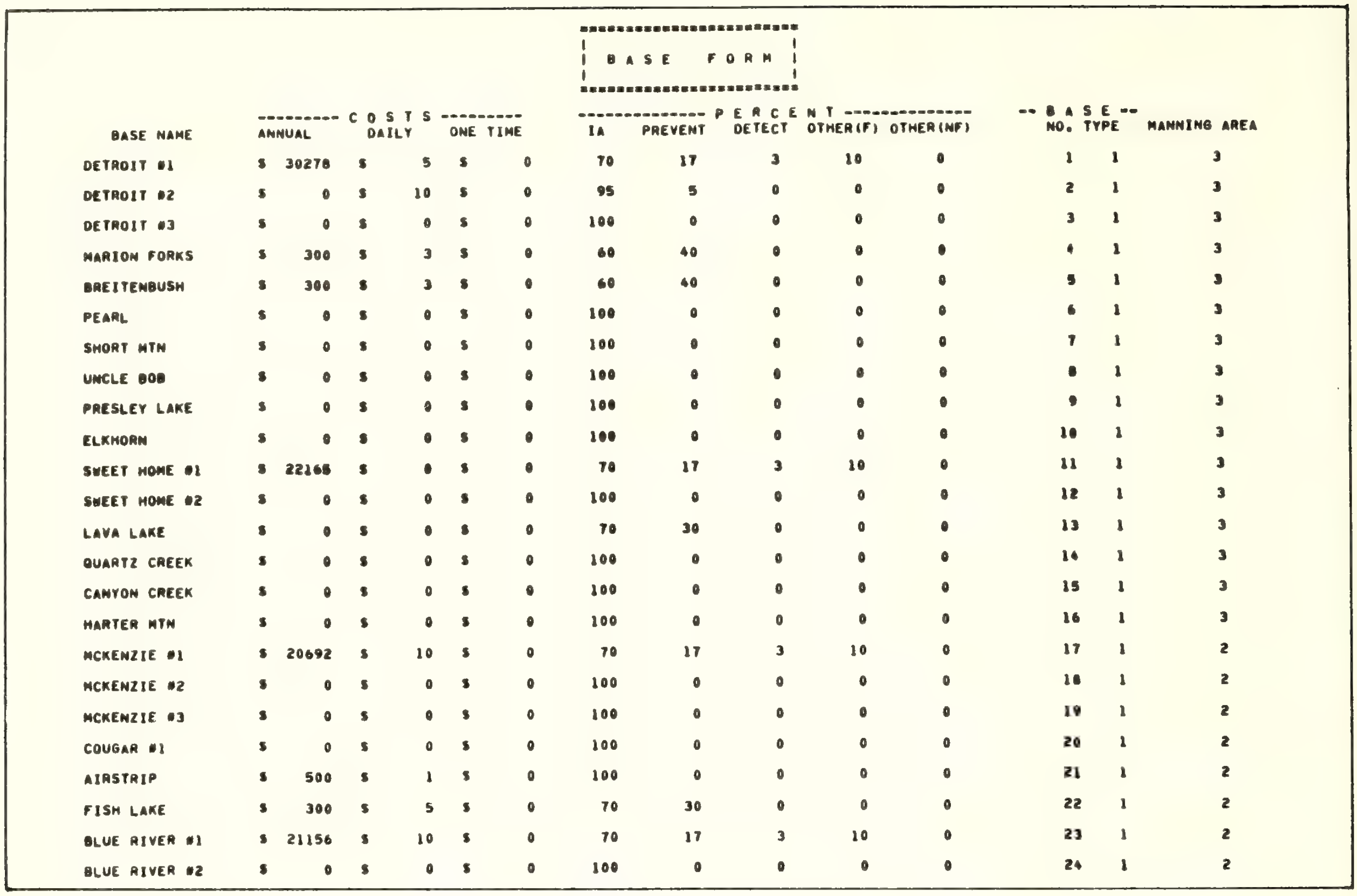
4.3.2 Individual Fire Summaries

SMOKEY II provides a transaction printout (*fig. 22*) which summarizes in one line the activities of each unit in the order they were dispatched to the fires and the costs related to the specific suppression action. The first line for each fire contains (on the right) the total acres burned and damages associated with this fire. Each unit is identified by its base, unit, and type numbers, and the crew size dispatched to the fire. Cost item definitions are discussed in the user manual (USDA Forest Service 1977c, ch. 10, sec. B).



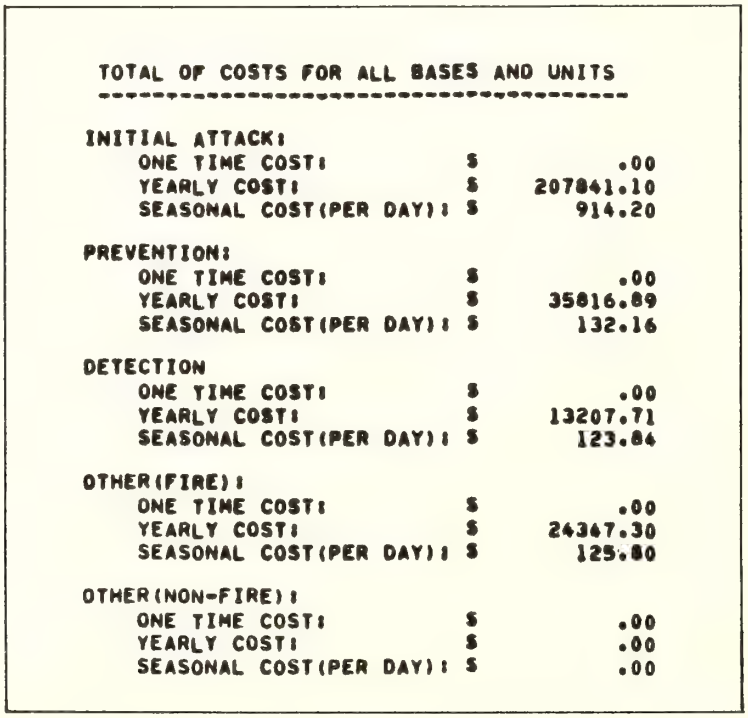
```
------------------------------------------------------------------------------------
OPTIONS IN EFFECT FOR PLAN SAN BERNARDINO NF A12 EXISTING REDUCED BY 50 PERCENT
------------------------------------------------------------------------------------



READ IN NEW COST CARDS, PRINT BASE & UNIT RATES

 1 SEASONS TO BE SIMULATED ON THIS RUN

SMOKEJUMPERS WALKOUT TIME IS 36 HRS.(TIME TO BE CHARGED)

PRINT OUT FIRE   SUMMARY

PRINT SUMMARY OF UNIT COSTS BY SEASON

PRINT SUMMARY OF UNIT COSTS BY SEASON

SEASON BEGINS ON JULIAN DATE 137

SEASON ENDS ON JULIAN DATE  319

CALCULATE OVERTIME AND HAZARD PAY
```

Figure 18—Example of cost module output: default options in effect under the Smokey II program.



```
                                                                   ========================
                                                                   |                      |
                                                                   |  B A S E   F O R M   |
                                                                   |                      |
                                                                   ========================

                             --------- C O S T S ---------         -------------- P E R C E N T --------------         -- B A S E --
     BASE NAME              ANNUAL       DAILY     ONE TIME         IA    PREVENT   DETECT  OTHER(F) OTHER(NF)           NO. TYPE    MANNING AREA

   DETROIT #1               $  30278   $       5   $      0         70      17        3        10        0                 1    1          3
   DETROIT #2               $      0   $      10   $      0         95       5        0         0        0                 2    1          3
   DETROIT #3               $      0   $       0   $      0        100       0        0         0        0                 3    1          3
   MARION FORKS             $    300   $       3   $      0         60      40        0         0        0                 4    1          3
   BREITENBUSH              $    300   $       3   $      0         60      40        0         0        0                 5    1          3
   PEARL                    $      0   $       0   $      0        100       0        0         0        0                 6    1          3
   SHORT MTN                $      0   $       0   $      0        100       0        0         0        0                 7    1          3
   UNCLE BOB                $      0   $       0   $      0        100       0        0         0        0                 8    1          3
   PRESLEY LAKE             $      0   $       0   $      0        100       0        0         0        0                 9    1          3
   ELKHORN                  $      0   $       0   $      0        100       0        0         0        0                10    1          3
   SWEET HOME #1            $  22168   $       0   $      0         70      17        3        10        0                11    1          3
   SWEET HOME #2            $      0   $       0   $      0        100       0        0         0        0                12    1          3
   LAVA LAKE                $      0   $       0   $      0         70      30        0         0        0                13    1          3
   QUARTZ CREEK             $      0   $       0   $      0        100       0        0         0        0                14    1          3
   CANYON CREEK             $      0   $       0   $      0        100       0        0         0        0                15    1          3
   HARTER MTN               $      0   $       0   $      0        100       0        0         0        0                16    1          3
   MCKENZIE #1              $  20692   $      10   $      0         70      17        3        10        0                17    1          2
   MCKENZIE #2              $      0   $       0   $      0        100       0        0         0        0                18    1          2
   MCKENZIE #3              $      0   $       0   $      0        100       0        0         0        0                19    1          2
   COUGAR #1                $      0   $       0   $      0        100       0        0         0        0                20    1          2
   AIRSTRIP                 $    500   $       1   $      0        100       0        0         0        0                21    1          2
   FISH LAKE                $    300   $       5   $      0         70      30        0         0        0                22    1          2
   BLUE RIVER #1            $  21156   $      10   $      0         70      17        3        10        0                23    1          2
   BLUE RIVER #2            $      0   $       0   $      0        100       0        0         0        0                24    1          2
```

Figure 19—Example of cost module output: base costs under the Smokey I program.



```
     TOTAL OF COSTS FOR ALL BASES AND UNITS
     --------------------------------------

   INITIAL ATTACK:
       ONE TIME COST:              $          .00
       YEARLY COST:                $    207841.10
       SEASONAL COST(PER DAY):     $       914.20

   PREVENTION:
       ONE TIME COST:              $          .00
       YEARLY COST:                $     35816.89
       SEASONAL COST(PER DAY):     $       132.16

   DETECTION
       ONE TIME COST:              $          .00
       YEARLY COST:                $     13207.71
       SEASONAL COST(PER DAY):     $       123.84

   OTHER(FIRE):
       ONE TIME COST:              $          .00
       YEARLY COST:                $     24347.30
       SEASONAL COST(PER DAY):     $       125.80

   OTHER(NON-FIRE):
       ONE TIME COST:              $          .00
       YEARLY COST:                $          .00
       SEASONAL COST(PER DAY):     $          .00
```

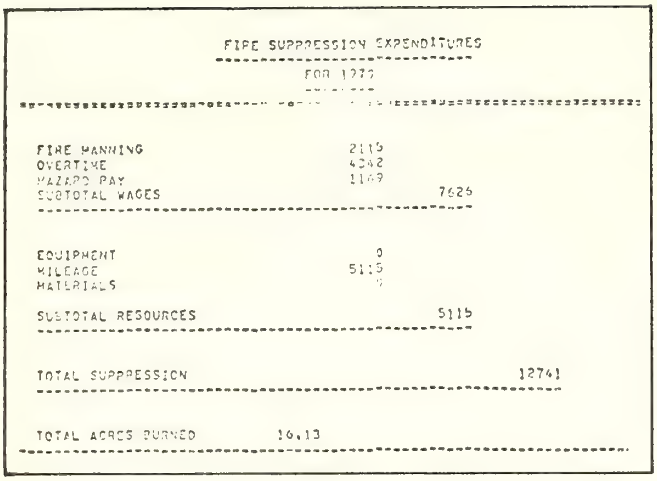
Figure 21—Example of cost module output: total costs under the Smokey I program.

```
                                                            ===========================
                                                            |  U N I T    F O R M - I  |
                                                            |                          |
                                                            ===========================
                 SAL/DAY                                    MXCR VS MNGUAR      CREDIT        - NO CREDIT -
   UNIT NAME     MNC 1XM      OT CST    A CST   GMN/YR       /YEAR  /DAY    C/DAY C/HR  B    C/DAY C/HR  B     CST/UNIT   U CR  B  U# TP B#

 DETROIT FMO          8   0        0        0        0           0     0        0    0 0        2    0 0           12   1  1  1   1  1  1

 DETROIT FMO          8   0        0      136        0           0     0        0    0 0        2    0 0           12   1  1  1   2  1  1

 DETROIT AFMO        63   0        0        0        0           0     0        0    0 0        2    0 0           12   1  1  1   3  1  1

 DETROIT AFMO        63   0        0      136        0           0     0        0    0 0        2    0 0           12   1  1  1   4  1  1

 DET PREV ASST       63   0        0        0        0           0     0        0    0 0        2    0 0           12   1  1  1   5  1  1

 DET PREV ASST       63   0        0      136        0           0     0        0    0 0        2    0 0           12   1  1  1   6  1  1

 DET TANKER         124  38        0      776        0           0     0        0    0 0        5    0 0           45   1  1  1   7  2  1

 DET SUPP CREW      365  33        0      600        0           0     0        0    0 0        3    0 0           16   1  1  1   8  1  1

 DET HELO CREW      200  38        0      600        0           0     0        0    0 0        3    0 0           16   1  1  1   9  1  1

 DET PROJECT        365  33        0        0        0           0     0        0    0 0        0    0 0           16   1  1  1   1  1  2

 RDET SC #1           0  48        0       60        0           0     0        0    0 0        2    0 0           12   1  1  1   2  1  2

 DET SC #2          144  48        0       60        0           0     0        0    0 0        2    0 0           12   1  1  1   3  1  2

 DET CAT             96  48        0       60        0           0     0        0    0 0      500    5 2            0   0  1  1   4  3  2

 DET ENG TANKER       0  48        0        0        0           0     0        0    0 0        0    0 0           45   1  1  1   5  2  2

 DETROIT DEPL 1       0  90        0      500        0           0     0        0    0 0        3    0 0           16   1  1  1   1  1  3

 DETROIT DEPL 2       0  90        0      500        0           0     0        0    0 0        3    0 0           16   1  1  1   2  1  3

 DETROIT DEPL 3       0  90        0      500        0           0     0        0    0 0        3    0 0           16   1  1  1   3  1  3

 DETROIT DEPL 4       0  90        0      500        0           0     0        0    0 0        3    0 0           16   1  1  1   4  1  3

 MARION FPT           0  38        0        0        0           0     0        0    0 0        0    0 0           16   1  1  1   1  2  4

 MARION FPT          38  38        0      263        0           0     0        0    0 0        3    0 0           16   1  1  1   2  2  4

 MARION SC #1         0  48        0       30        0           0     0        0    0 0        0    0 0           12   1  1  1   3  1  4

 BREITEN FPT         38  38        0        0        0           0     0        0    0 0        0    0 0           16   1  1  1   1  2  5

 BREITEN FPT         38  38        0      263        0           0     0        0    0 0        3    0 0           16   1  1  1   2  2  5

 PEARL FPT           38  38        0        0        0           0     0        0    0 0        0    0 0           16   1  1  1   1  2  6
```

Figure 20—Example of cost module output: unit costs under the Smokey I program.

```
-------------------------------------------------------------  ---------------------------------------------------------------
     EACH TRANSACTION FOR PLAN:  SAN BERNARDINO BASE PLAN                                                         YEAR 1970
-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------------

          ****  FIRE NO.     1  ****

BASE  UNIT  UNIT  NO.     FIRE        OVER       HAZARD      EQUIP       MILE     MATERIAL      TOTAL     POTENTIAL    BURNED
NO.   NO.   TYPE  MEN   MANNING       TIME        PAY        COST        COST       COST      SUPPRESSION   DAMAGE      ACRES
----  ----  ----  ---  ----------  ----------  ----------  ---------  ---------  ----------  ----------  ----------  ----------

 43     1     2    8         .00         .00         .00        .00        .00         .00         .00         .00          .00
 43     2     2    8         .00         .00         .00        .00        .00         .00         .00
 42     1     2    5         .00         .00         .00        .00        .00         .00         .00
 21     1     2    5       50.34         .00       12.59        .00      40.25         .00      103.18
  8     2     2    2       26.58         .00        6.65        .00      34.20         .00       67.43
 14     2     2    2       27.07         .00        6.77        .00      36.00         .00       69.83
  3     2     2    2       27.31         .00        6.83        .00      36.90         .00       71.04
  3     1     2    5       64.97         .00       16.24        .00     100.05         .00      181.26
-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------------

          ****  FIRE NO.     2  ****

BASE  UNIT  UNIT  NO.     FIRE        OVER       HAZARD      EQUIP       MILE     MATERIAL      TOTAL     POTENTIAL    BURNED
NO.   NO.   TYPE  MEN   MANNING       TIME        PAY        COST        COST       COST      SUPPRESSION   DAMAGE      ACRES
----  ----  ----  ---  ----------  ----------  ----------  ---------  ---------  ----------  ----------  ----------  ----------

 56     1     2    4         .00         .00         .00        .00        .00         .00         .00        2.40          .00
 55     1     2    4         .00         .00         .00        .00        .00         .00         .00
 41     1     2    5         .00         .00         .00        .00        .00         .00         .00
 42     1     2    5         .00         .00         .00        .00        .00         .00         .00
 39     1     2    5         .00         .00         .00        .00        .00         .00         .00
  8     2     2    2         .00       36.25        6.04        .00      11.70         .00       53.99
 21     1     2    5         .00       86.91       14.48        .00      36.80         .00      138.19
  3     1     2    5         .00       90.28       15.05        .00      46.00         .00      151.33
-------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------------

          ****  FIRE NO.     3  ****

BASE  UNIT  UNIT  NO.     FIRE        OVER       HAZARD      EQUIP       MILE     MATERIAL      TOTAL     POTENTIAL    BURNED
NO.   NO.   TYPE  MEN   MANNING       TIME        PAY        COST        COST       COST      SUPPRESSION   DAMAGE      ACRES
----  ----  ----  ---  ----------  ----------  ----------  ---------  ---------  ----------  ----------  ----------  ----------

 59     1     2    5         .00         .00         .00        .00        .00         .00         .00         .00          .00
 59     2     2    5         .00         .00         .00        .00        .00         .00         .00
 61     1     2    5         .00         .00         .00        .00        .00         .00         .00
 11     1     2    5       54.28         .00       13.57        .00      27.60         .00       95.45
 35     1     2    5         .00         .00         .00        .00        .00         .00         .00
 41     1     2    5         .00         .00         .00        .00        .00         .00         .00
 42     1     2    5         .00         .00         .00        .00        .00         .00         .00
```

Figure 22—Example of cost module output: individual fire printouts.



```
                    FIRE SUPPRESSION EXPENDITURES
                    -----------------------------
                              FOR 1977
                              --------
==================================================================

  FIRE MANNING                          2115
  OVERTIME                              4342
  HAZARD PAY                            1169
  SUBTOTAL WAGES                                  7626
  ------------------------------------------------------

  EQUIPMENT                                0
  MILEAGE                               5115
  MATERIALS                                0

  SUBTOTAL RESOURCES                              5115
  ------------------------------------------------------

  TOTAL SUPPRESSION                                         12741
  ---------------------------------------------------------------

  TOTAL ACRES BURNED          16.13
------------------------------------------------------------------
```

Figure 23—Example of cost module output: summary of seasonal fire suppression expenditures.

This listing has several characteristics which should be mentioned. What appears to be a discrepancy between the dispatch list of the suppression module and this transaction list occurs when helicopters are deployed. Instead of showing one transaction each time a helicopter is used, two transactions are usually generated to allow separate costing of the crew and helicopter units. All costs related to their suppression activities are accumulated before the helicopter-related costs are considered.

Instead of listing the crew size dispatched under the *MEN* category for an air tanker, the total number of loads carried on this fire is indicated. Thus, the program waits until the last air drop is registered by this air tanker. The air tanker which therefore makes more than one drop does not appear in the transaction list in the same order or as many times as in the dispatch list. A helicopter might also appear fewer times on the transaction list if it is used to shuttle more than one crew to a fire. This results from the method used to keep track of helicopter time and to avoid overcharging flight time on multiple flights.

4.3.3 Fire Suppression Expenditures

Fire suppression expenditures (*fig. 23*) are always printed regardless of the options selected. This printout breaks down the total suppression cost for every season simulated in SMOKEY II. The items listed in the summary are season totals of the fire summary listing.

4.3.4 Base and Unit Summary

The base and unit cost printout (*fig. 21*) groups all units in the plan by base type and lists corresponding data for each season. Besides giving the base and unit numbers and the unit name, the printout indicates any funds from contract agreements which were not used during the season (not subtracted from the minimum guarantee on non-dispatch days.[3] Also displayed are normal staffing costs, suppression costs, and the number of fires the unit was dispatched to. Five other categories are filled in according to unit type: *MILES TRAVELED* and *TIME/MAN HR* by ground crews, *TIME/MAN HR* by plows and dozers, *# OF TRIPS* by helicopters (should be greater than or equal to *# OF FIRES*), *# OF MEN SENT* by smokejumpers, and *# OF RET LOADS* by air tankers.

4.3.5 Cost Summary

The cost summary (*fig. 16*) appears regardless of the option selected. This summary lists the fixed costs, variable costs, and damage potential for one season. The cost summary is an improper means of comparison if, for the purposes of debugging, only a portion of the fire season is costed. The variable cost and damage potential would then reflect only a portion of the season's fires.

5. LARGE FIRE GAMING

Although FOCUS provides a realistic simulation of fire behavior and suppression forces for small fires, the computer model cannot realistically handle large fires. No computer model is currently available that can reliably simulate the actions of large fires. The reasons are several:

- Large fires burn through drastically different weather, fuel, and topography conditions.
- Fire control strategies differ between fire bosses and are almost impossible to generalize and model.
- Firefighting forces on a large fire may not be part of the fire plan and availability can be unpredictable, particularly when cooperators and military are used.

Large fire simulation is supported by FOCUS but must be gamed by fire experts using local knowledge, experience, and judgment. Moreover, the gamers are constrained by a standardized set of procedures.

Despite the expense of gaming large fires (it requires bringing together a team of knowledgeable people for several days), some FOCUS planners have used the procedure as a training exercise for personnel prior to the fire season.

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[3] Some equipment is hired on a commitment or minimum guarantee for a day or an entire season from an independent contractor, for example, a contracted bulldozer or helicopter. Depending on the contract, hourly or daily credit is charged against this contract as the equipment is used or in some cases a charge in addition to the guarantee. FOCUS can cost out various combinations of such contracts.

5.1 Input Requirements

FOCUS considers escaped fires to be large or long duration fires, usually 100 acres or more (the actual values are input parameters), that must be handled by the gaming procedures. The escaped fires to be gamed are located and plotted on topographic maps. The FOCUS suppression module output will provide a summary of forces already on the fire and those forces that have been dispatched but not yet arrived. The FOCUS suppression module also provides the fire size at a given time and the amount of held line.

The materials needed for large fire gaming include:

- Topographic maps of the fire area scaled 2 inches to the mile or 4 inches to the mile and aerial photographs of the fire area.
- FOCUS printouts summarizing fire activity by alternative plans.
- Maps or overlays of fuel models, fuel types, or vegetative cover types in the area.
- Maps or overlays of resource damage potential classes, values-at- risk, or other display of potential economic loss from fire.
- Hand-held calculator for fire behavior characteristics, such as the Texas Instrument Model TI-59 with the fire danger/fire behavior Custom Read Only Memory.[4]
- Fireline Notebook or other means of calculating rates-of-spread of fires and fireline construction and holding rates.
- Diurnal weather change information.
- Draftsman's compass, protractor, scale, colored pencils, pens, and planimeter.
- Copies of the FOCUS baseline fire information worksheet (form 43), escape fire calculation sheet (form 44), and perimeter-acreage form (USDA Forest Service 1977c).
- Approved suppression cost figures for the unit, based on average or actual costs which in turn are estimated on a per acre, per chain of held line, per hour, or per mile basis. The Forest Service Morning Report and other sources may be used.
- FOCUS dispatch priorities for the plans or alternatives being evaluated.

5.2 Output Summaries

The gamer's objective is to calculate the final size and shape of the fire(s) that would result under the various proposed alternative plans. The same fire may have to be gamed several times, once for each alternative that results in an escape. One baseline fire must be calculated in order that the results be as objective as possible and the comparisons between alternatives be as realistic as possible. This baseline fire is simply the gamer's recorded (mapped) estimate of what each FOCUS escaped fire would look like over time with no suppression action after the fire reached escape conditions.

Hourly calculation of the baseline fire's perimeter should consider the variations in rates-of-spread (ROS) under causes such as slope, aspect, fuel changes, weather, and natural or manmade barriers. The gamer is free to select the direction and shape of the baseline fire based on his knowledge and experience of the fire area. Once the gamer has plotted the baseline fire perimeters by hour, he can estimate the effectiveness of suppression actions against that fire. Implied in each alternative fire plan are some differences in forces, locations, or other components; therefore, resultant gaming of baseline fires gives some differences in the fire size, forces required for control, and costs.

Worksheets are provided to guide the gaming task. After final perimeters are calculated for all alternatives to be tested, the cost and damage figures are entered on the appropriate forms.

Gamers and planners can prepare a variety of escape fire summaries after gaming results are recorded in order to compare performance of alternatives (*table 3*). These summaries include data from the following sources:

Year/day	Fire workload year and Julian date of escape fire.
Fire number	FOCUS sequential fire number found in suppression module output.
Value class	Resource damage potential class; in this case, 2 means $500/acre (USDA Forest Service 1977c, table 3.1).
Acres burned	Data from large fire gaming process, form 44, item 12 (USDA Forest Service 1977c, sec. 6.7).
Damage potential	Acres burned multipled by value class. An alternative is to use agency's own damage estimation procedures.
Suppression cost	Data from large fire gaming process, form 44, item 11 (USDA Forest Service 1977c, sec. 6.7).
Cost plus loss	Damage and suppression cost columns added (for National Forest only).
State acres burned	Extra information for other agency cooperators.

The sample summary worksheet included here (*table 3*) provides data on five escaped fires which occurred on National Forests and Grasslands during 4 nonconsecutive years (State fires are shown in parentheses). These escaped fires burned a total of 495 acres, inflicted $446,500 in damages, and resulted in suppression costs totaling $69,600. Cost-plus-loss for the planning unit considered in alternative A totaled $516,150.

The unit participated also on six adjacent State escaped fires. In State fires, only the State acres burned are calculated, in this case 580 acres.

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[4] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

Table 3—*Summaries of escape fires, entered on worksheets, alternative A*

Year/ Julian day		National Forest and Grassland						State acres burned
		Fire No.[1]	Value class[1]	Acres burned	Damage potential	Suppression cost	Cost plus loss	
					Dollars			
[2]61-122		(5)	(2)	—	—	—	—	3
61-194		84	2	30	15,000	5,984	20,984	—
61-194		(86)	(1)	—	—	—	—	390
61-273		(308)	(2)	—	—	—	—	2
Subtotal 61	1	(3)	—	30	15,000	5,984	20,984	395
67-169		(15)	(3)	—	—	—	—	45
[2]67-291		230	3	6	6,000	6,830	12,830	—
Subtotal 67	1	(1)	—	6	6,000	6,830	12,830	45
[2]69-047		(1)	—	—	—	—	—	—
[2]69-106		4	3	6	6,200	6,800	13,000	—
69-245		228	3	408	408,100	47,956	456,056	122
Subtotal 69	2	(1)	—	414	414,300	54,756	469,956	122
[2]70-122		(6)	(1)	—	—	—	—	18
70-155		57	1	45	11,250	2,030	13,280	18
Subtotal 70	1	(1)	—	45	11,250	2,030	13,280	18
Total	5	(6)	—	495	446,550	69,600	516,150	580

[1] State fires shown in parentheses; damage not calculated for such fires.

[2] Fire escaped before and after the official fire season.

Four assumptions are important to remember during gaming:

- Gamers are free to use their own expertise and knowledge of fire behavior to predict where and how fast the baseline fire will go.
- Gamers are also free to order suppression resources not included in the fire plan being evaluated, provided that such forces are traditionally used in real life, and their orders would be considered reasonable under actual conditions.
- Gamers should not materially change tactics or strategies when attacking the same baseline fire with forces from alternative proposals. General strategy should be decided for the first exercise just as though the gamer were on the scene of a real fire. That same general strategy should be followed every time the fire is gamed. The temptation is to change strategies after completing the first exercise and to apply the learning in the next tactic, but that defeats the purpose of objectively testing plan against plan.
- Gamers can use two methods for determining suppression costs: Direct calculations using the workup forms provided and instructions given in the User Manual (USDA Forest Service 1977c). Generalized fire size-cost curves that have been developed by various regions (*fig. 24*).

5.3 Deviating from Established Procedure

Care and quality work is essential in large fire gaming because 75 to 90 percent of the costs and damages incurred by agencies are for fires that exceed escape parameters. Careless work or bias toward a particular

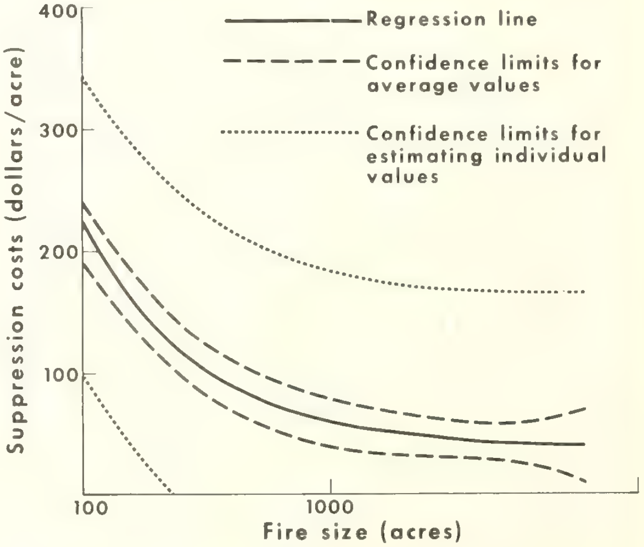

Figure 24—By relating suppression cost to fire size, as in this California Department of Forestry example, generalized curves can be developed.

Table 4—*FOCUS Support programs and applications*

FORTRAN programs	Input data set	Data source	Output	Remarks
CONVERT	Road network	Node map	Node number, X, Y value	Use optional; requires minor modification by each data set.
	Fire occurrence	Fire location map	Fire number, X, Y value	
	Off-road barrier	Barrier location map	Barrier number, X, Y value	
COMBINE	Road network	Convert output, coded data	Complete road network	Use optional; requires minor modification by each data set.
	Fire occurrence	Convert output, FORMS output	80 pct. of fire occurrence	
	Off-road barrier	Convert output, coded data	Complete off-road barriers	
CHECKNET	Road network	Combine output	Consistency errors	Required
PLOTROAD	Road network	Verified data	100 pct. verified road net	Required
SORT	Fire occurrence	Combine output	Chronologically sorted fires	Use optional
FIRECARD	Fire occurrence	Sort output	Verified fire occurrence	Required
ZEDIT	All suppression module data sets	All suppression input	Verified suppression input	Required
SMOKEY I	All cost module data sets	All cost input	Fixed cost and verified	Required

alternative can result in erroneous conclusions. A major concern of all FOCUS system users must be impartiality during the gaming process.

If an unbiased team applies the gaming techniques outlined in the User Manual, each alternative should be tested against the same set of assumptions and the outcome of the alternatives minimally should be ordered according to their relative effectiveness.

Another concern is that FOCUS uses the seven damage potential classes developed for the 1972 Fire Plan. The acres burned in each damage potential class are multiplied by the appropriate class value, the sum of which gives the total damage for the fire. General agreement in the Forest Service is that these values are too high; yet this system is a national standard and at present no other damage calculation procedure is accepted. Large fire damage tends to be so great that it masks variations in costs and damage in small fires and suppression costs in large fires. To retain its currency, the FOCUS system should continually update its fire damage data as new information is learned or made available.

Most users have tended to date to use generalized cost-fire size curves (*fig. 24*) rather than the FOCUS worksheets when the former are available. Regarding the accuracy of this technique, Flatman and Storey state, "Based on the size of the calculated confidence intervals for average costs, one would conclude that the cost-fire size curve is an acceptably accurate source for costing gamed fires."[5]

The authors point out that such accuracy is only available when several years of large fires are gamed and average costs for large fires are used. FOCUS simulation results are interpreted as averages. FOCUS simulates and games fires individually, but it claims to match the real world fire situation only on the average.

6. SYSTEM SUPPORT PROGRAMS

The FOCUS system requires a specific data base which is a compilation of information such as road network, fire occurrence, fire resources, dispatch plans, and cost data. The FOCUS data base relies on a variety of sources, and applies a variety of methods to collect and process these data, depending on the particular planning unit. The FOCUS support programs provide for one method to process and verify the needed data (USDA Forest Service 1977c).

The support programs consist of eight small FORTRAN programs (*table 4*). Five of these programs are editing routines and must be used by all FOCUS users. Suppression module data are checked using programs FIRECARD, CHECKNET, PLOTROAD, and ZEDIT. Program SMOKEY I lists cost data for manual verification. The remaining three support programs convert source data into the FOCUS data specifications and may have to be modified to meet specific needs, depending on data sources.

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[5] Flatman, George T., and Theodore G. Storey. 1977. Are generalized cost-fire size curves adequate for costing escape fires in FOCUS simulation? Unpublished manuscript. U.S. Dep. Agric. Forest Serv., Pacific Southwest Forest and Range Exp. Stn., Riverside, Calif.

7. APPLICATION

7.1 User Requirements

FOCUS is an operationally tested, computer-based simulation which enables planners to compare one initial attack system against another in cost-effective terms. The level of effort involved in transferring this technology to the user has been impressive, including training sessions, seminars, management briefings, and personal conferences. Also, research has published a user and technical documentation series designed to assist the user in applying the FOCUS technology at the operations level:

Documentation	*Audience*
Executive Brochure	Policy and legislative level
Fire Manager's Guide	Fire managers
User Manual	Fire specialist and computer specialist at planning unit level
Forms Guide	Fire specialist and computer specialist at planning unit level
Documentation System	Communications at overhead levels
Documentation Control and Software Maintenance Manual	National user support staff level

The Fire Manager's Guide (USDA Forest Service 1977a) explains who should use FOCUS and addresses decisionmaking concerns of the prospective user relating to FOCUS impact on budget, staff, and project objectives. Chapter 2 of the Fire Manager's Guide discusses general considerations, a decisionmaking checklist, and estimates operational start-up costs.

In operational tests to date, the FOCUS system has accommodated all planning unit sizes, large geographical units (Bureau of Land Management, Alaska), heavy fire occurrence units (Rome Unit, Georgia), State Forestry Commission and high density road network units (San Bernardino National Forest, Pacific Southwest Region, Forest Service).

FOCUS is a complex, expensive, and demanding tool. Three ingredients must be present to make FOCUS a worthwhile undertaking—need, motivation, capability:

- Need. The costs of initiating FOCUS are largely dependent on the size—particularly of the transportation system and fire organization—and fire workload of the unit. Some agencies probably do not have sufficient fires to make it worthwhile.
- Motivation. Persons at all levels of the FOCUS effort must be motivated. This is particularly true of high level management within the planning unit.

  The FOCUS effort will surely fail if an unmotivated employee is given the task to "fit it in" as best he can.
- Capability. FOCUS demands availability of a computer system with a high-speed line printer and card reader. Ideally, these should be available without undue travel time. A computer specialist and a fire specialist are needed. The fire specialist (or whoever is assigned the principal data collection job) should be analytically oriented, with a strong interest in systems analysis. The computer specialist should be familiar with the FORTRAN programming language and data handling techniques.

7.1.1 Developing In-House Experience and Hardware

Successfully introducing FOCUS technology into user organizations depends heavily on recruitment of quality specialist personnel and establishing a compatible organizational environment. Of 23 operational tests to date, five have been relative failures. In every case, the inability to achieve targets can be attributed directly to management breakdowns or recruitment of unqualified personnel. Testing experience indicates that about one-fourth person-year of computer specialist time is needed to start up FOCUS for a planning unit. About one-half to three-fourths user-year of fire specialist time is required. Most of the fire specialist time should be expended at the planning unit level, with some staff time invested at higher levels for purposes of policy direction and training.

FOCUS staffing requirements are defined in the Fire Manager's Guide (USDA Forest Service 1977a, ch. 3). The fire specialist and computer specialist operate as a team under the technical direction of the top level fire managers at the planning unit and higher levels. Users generally have not established the technology at most organizational levels, therefore a FOCUS technical support staff has been made available to provide user support and interpret system documentation. During operational testing, this support service was provided by research at the Forest Fire Laboratory, Riverside, Calif. FOCUS is currently maintained by a systems support staff at the Boise Interagency Fire Center, in Idaho. Until the technology is sufficiently established at regional levels, such support will be necessary. Once the resident technical capability at regional and local levels is established, users may want to reduce national technical support to a level which permits only system maintenance and policy control.

The local fire specialist performs several functions that are essential to the success of FOCUS under management policy and direction. First, he guides the selection of historical fire seasons to be simulated. Second, he helps shape fire management strategies for the alternatives to be studied. Third, he directs the tasks of gaming and estimating large fire costs. These tasks exceed FOCUS computer modeling capability but are nevertheless essential to establishing comparisons of initial attack combinations in terms of total cost effectiveness.

The computer specialist should have recent training in FORTRAN programming. He will supervise data entry, develop small-scale data manipulation programs, control computer runs, correct computer files, cooperate with regional or national technical support groups, and assist in interpreting results.

The largest FOCUS task often is road network data collection. Field technicians are responsible for collecting most of these data. The extraction of fire data from individual fire reports, normally done by dispatcher personnel, is also a major task. These two technician level jobs total about 95 percent of the data collection effort.

In-house hardware capability is now available in the Forest Service systemwide. The computer specialist who represents the planning unit needs a high-speed terminal for access to the Fort Collins Computer Center. States and other agencies can arrange to use these facilities through USDA contracts.

7.1.2 External Maintenance and Support

The FOCUS Maintenance Manual (USDA Forest Service 1978a) is part of the technical documentation provided by research. This manual was mostly prepared by program authors of the suppression and cost modules to provide detailed explanations of computer programs for use by FOCUS computer support personnel.

Continued, close technical liaison was required between program authors and the Forest Service operational support group during the first year of implementation. Production-oriented program modifications and debugging problems are not direct research problems; however, minimum consulting time between research and operations was anticipated and programmed during the first operational year.

7.2 Implementing FOCUS: Principal Tasks

The successful use of FOCUS depends on the joint efforts of technicians, specially trained FOCUS specialists, fire managers, and land management unit decisionmakers. These leadership positions are charged with the responsibility of developing within the user organization the technical expertise required for FOCUS performance. The organization also needs a dynamic fire planning policy which permits consistent and flexible application of the new technology on either the state or national levels.

The principal FOCUS tasks are:

- Planning
- Data collection, entry, and verification
- Storing travel times
- Running and validating the base plan
- Running the cost module
- Running alternatives
- Escape fire gaming
- Analysis and interpretation of results
- Presentation to management.

7.2.1 Planning

The FOCUS User Manual states, ''Planning for the use of FOCUS is as critical to success as is planning for the suppression and control of actual fires.'' This advice is no doubt true since failure to plan can result in unnecessary expense amounting to thousands of dollars. Prior to implementation, the fire specialist should spend several days planning and scheduling the FOCUS operation, with particular attention to the following points.

The planning unit may be the agency's or organization's administrative unit, but can also include cooperators, agency personnel not normally assigned to fires, and joint planning areas such as parts of several National Forests. The FOCUS approach will differ depending on organizational objectives: to analyze and fine tune the agency's organization, or to participate in a national policy or economic analysis. Where national objectives are concerned, both time and requirements may be rigidly structured.

Certain considerations pertain to all levels of effort, specifically, selecting an appropriate fire workload, maximizing utilization of agency personnel and resources, and effecting a productive relationship with cooperators. Program alternatives may be freely selected within this framework, except in the case of budget analysis which operates under more rigidly established guidelines.

Selecting, training, and managing personnel is the key to FOCUS success and efficiency. Personnel must be analytical, motivated, experienced in the planning unit operations, and provided with adequate blocks of time without interruption.

FOCUS requires considerable historical information, the generation of new data such as travel times, and conjecture based on past performance. To this end, the planner needs to assess available resources in light of program objectives and thereby determine how to maximize system performance and achieve reasonable levels of accuracy.

Understanding how an organization works poses a major challenge to some planners. Despite policy guidelines, many unwritten procedures contribute importantly to the philosophy governing an organization's policy and practices. For example, dispatch procedures to high value areas, use of cooperators, and delay factors are all important, but written procedures in these areas do not always determine what is practiced. Many such items make up the general run parameters that are crucial to FOCUS (USDA Forest Service 1977c). For this reason, the planner should devote considerable effort in determining run parameters which respond to an agency's specific requirements.

Large fires may comprise 95 percent of an agency's damage and suppression costs, making it imperative that escaped fire be gamed. Such gaming may entail considerable planning since a team of experts have to be assembled for several days. Budgeting money and time is also required. The planner may be able to offset gaming expenses if the gaming effort is conducted as a training session.

7.2.2 Data Collection and Entry

Data collection is at once the single largest task in setting up the FOCUS planning unit and the most underestimated by management. Transportation network data represents the most comprehensive area of the data collection effort. Travel times between nodes are recorded for three weight classes of vehicles and for foot travel on trails. Fire history data collection is the second major job and can be compiled from individual fire reports.

Agency procedures and rules governing actions such as dispatching and staffing under various conditions need to be translated into decision tables and entered into the FOCUS data bank. For example, these rules describe the use of secondary forces (such as an engineering crew or rural fire department engine), availability, application to specific types of fire, and dispatching requirements.

The Fire Manager's Guide for FOCUS (USDA Forest Service 1977a) estimates time commitments for these tasks. The FOCUS User Manual (USDA Forest Service 1977c) provides step-by-step instructions.

Three methods are used to assemble computer data:

- Transportation node and fire locations are usually converted to data files in either tape or keypunch card form using digitizing equipment.
- Some of the fire occurrence data may be retrieved from computer files of individual fire reports.
- All other data are entered on special data coding forms that are then used to prepare keypunch cards. The digitizing and keypunch operations can normally be contracted for on an as-needed basis.

The data is put on keypunch cards or some form readable by the computer which can then be verified by the fire editing programs. These programs check for missing data and for incorrect values or numbers. The ZEDIT and the SMOKEY I programs help ensure that the data is correct for the suppression and cost modules.

7.2.3 Storing Travel Times

The travel times of all ground units to the fires need to be calculated only once. The STORETT program uses the road network, fire occurrence, and ground base location data to calculate and store the travel times from all bases to all fires. These data are computer stored for further use on alternative runs. The travel times must be recalculated if a base location is moved, a road segment is modified, or a fire location is repositioned. This step is expensive and time consuming; therefore, the user should plan ahead for any changes and include potential base locations and road segments in the data. These potential data items can then be used or omitted for any particular plan alternative.

7.2.4 Running and Validating the Base Plan

Running and validating the base plan is perhaps the most critical step in FOCUS. This procedure verifies that the simulation model data are correct and that the user understands the simulation model operation. Validation is a two-step process. First, the data are verified before running the simulation model. Second, a limited simulation run is made using only a limited number of the historical fires.

Data validation, the first step, uses edit routines to check data for accuracy, consistency, and conformance to FOCUS program requirements. The intent is to isolate discrepancies caused by a variety of human errors during the data collection phase.

Simulation validation, the second step, involves running a base plan to test all operational rules programmed for a specific run, including dispatching rules, staffing rules, and use of secondary resources. The base plan must be tested for data errors and accuracy of planning assumptions prior to running alternatives. Two computer reports must be considered: the resource arrival sequence for each fire, which list the sequence of actions taken to fight each fire, and the use tally for equipment and crews at each base during each fire season. This task is usually more difficult than data validation. The users need to ascertain that the FOCUS model is appropriately deploying resources and fighting fires which have recently occurred.

A FOCUS team usually consists of a computer specialist, a fire specialist, and several planning unit personnel. This team runs the suppression module using their input data and reviews the output fire by fire in order to validate the base plan.

These validation teams inspect output to determine the reasonableness of model responses as compared to historical events. Differences must be explainable or correctable to ensure validation of the simulation; however, not every model fire replicates a historical event. For example, in real life, a dispatcher may erroneously have sent the wrong resource; or a given historical fire may have benefited from the fortuitous initial attack of a passing forest worker. FOCUS does not make mistakes, nor does it perform providential acts. The model simply processes a scenario based on defined assumptions and given input data. For that reason, the overall summary output of the model should be compared to an overall historical performance. The validation requires many hours of work and reruns on the computer. Mistakes in coding or interpretation of data often lead to false starts. However, this validation is a critical step that leads to success.

7.2.5 Running the Cost Module

The cost module may be variously run. In one method, all suppression module alternatives are run and analyzed prior to executing the cost module. The user is thus allowed to run the base plan and other plans of interest, then eliminate any alternatives that will not be considered for implementation before running the cost module.

In another approach, the cost module is run on the base plan and all alternatives, a method preferred for some planning units and alternatives.

7.2.6 Running Alternatives

Most fire organizations are adaptable: small changes relative to the size of the organization usually will not make much difference to overall damages or costs. Substantial differences normally show up only when alternative plans are significantly different. In FOCUS, alternatives were produced by adjusting several variables:

- Location of bases
- Mix of fire resource types
- Suppression objectives
- Dispatching plans and policies
- Mix of primary and secondary forces
- Use of cooperating agency forces
- Equipment and labor financing.

Summary outputs for alternative plans (number of escaped fires or total costs and damages) may not deviate dramatically from each other. These summaries need careful examination, whether or not they agree with the planners' initial bias and best guess. Data such as the fire workload assumption and variance in fire resources efficiency should be looked at in detail. An output with little or no change may simply mean that the alternative appears insensitive because the fire organization is already overstaffed; yet a closer look at internal utilization summaries may show a wide fluctuation in the use of key suppression resources.

A good set of alternatives requires both careful thought and bold imagination. And more than one attempt has been required in almost all tests to date to arrive at good alternatives. In other words, FOCUS is not an optimizing modeling system: a best choice is not discovered simply by selecting two or three alternatives for analysis and choosing the one that reflects the lowest cost. Studies of how the computer uses fire suppression resources to arrive at the results have led to substantial improvements in the original organization.

7.2.7 Escaped Fire Gaming

As pointed out in the large fire gaming section, the computer simulation process stops when a fire exceeds the escape parameters. The planning team determines the final suppression costs and resource damages by manual gaming. Gaming is required because the FOCUS computer model would not simulate reality accurately for large fires.

Undisciplined planners and managers sometimes oversimplify and de-emphasize the gaming process. Yet the gaming process, in addition to obtaining the needed large fire costs and losses, apprises a fire organization of the rationale and applicability of FOCUS to their planning unit. Gamers have learned why some fires escape and others do not, for example, why the perimeter of a given fire may be almost 100 percent contained at escape, yet the same fire in another alternative may escape with little or no line constructed.

7.2.8 Analyzing and Interpreting Results

Analyzing FOCUS output depends on the objectives of the study and the needs of the decisionmakers. Preliminary analyses should determine which of the alternatives show promise. Other alternatives may arise from these initial efforts. Results which appear anomolous must be investigated. Data or run setup errors and assumptions are always possible.

FOCUS analysts must remember that basic trade-offs exist between resource use and other results, such as acres burned or damage potential. Alternatives which show little change in costs and damages may show significant changes in resource use patterns. If these changes are not acceptable as in overuse of cooperator resources, a new alternative may have to be designed within the realm of acceptability while all other factors remain constant.

Although FOCUS provides several summary tables, specific analyses of resource use require extracting data from the individual fire printouts which are available from both the suppression and cost modules. For example, a detailed list of substitutions can be obtained for a resource unit which was removed in an alternative procedure.

The FOCUS analyst should become sufficiently familiar with the results of alternative plans that he can confidently explain any reasonable questions which might arise.

7.2.9 Management Presentation

The interaction between FOCUS technical efforts and agency management is crucial. Operational testing is most effective where decisionmakers are continually involved. Decisionmakers provide land management input and require accomplishment of specific attainable objectives.

Therefore, how fire managers summarize and display FOCUS output to decisionmakers is important. The system can be a tremendous aid to managers and planners but only if the results are comprehensible. Top management—such as a State land management director, National Forest supervisor, or State region administrator—will have had far less time to understand FOCUS output than the team members who are working with FOCUS daily. The output must be as free as possible from jargon peculiar to FOCUS, and the information presented must have some direct bearing on relevant management issues.

Meetings with top management are in three stages: initial planning, alternative evaluation, and final review. In initial planning, a variety of topics is discussed, including objectives, organizational requirements, base plan review, historical fire workload selection, planning unit

Table 5—*Cost-plus-loss comparison for planning alternatives*

Alternative	Cost	Loss	Total
		Millions of dollars	
A	3.083	0.153	3.236
B	1.862	.461	2.323
C	1.031	.654	1.685
D	0.625	.955	1.580
E	.740	.802	1.542

selection, and alternative plans. This loosely structured meeting should address all pertinent issues and ramifications. Salient issues must be clearly defined and documented. Agreement on program objectives is foremost: the success of various planning unit alternatives are measured against these objectives. Acceptable individual, variable, or cumulative fire losses and economic objectives are determined at this time.

In alternative evaluation, the second stage, initial FOCUS results are presented and evaluated. These results should include a base plan and related alternatives. Evaluation results should be supported by well-developed summary and fact sheets and illustrations as necessary. Agreement must be reached on changing and adding alternative plans and on constraints in the further design and testing of alternatives. Planning objectives are clarified and modified.

Final review is the third and final stage. Here, one of the alternatives, if acceptable, can be selected for implementation; however, if further work is required, additional second stage evaluation can be made. The presentation of a rough-draft final report is recommended, which will provide information for management policy and program changes. Despite the critical nature and urgency of the final review, very few users have availed themselves of this management tool. Heavy reliance has been put on informal communications and briefings. Agency leaders must enforce adherence to report standards and policy to achieve conformance by individual planning units in this area.

7.3 FOCUS Cost-Effectiveness Evaluations

FOCUS output summarizes fixed costs, variable costs, and potential damages for each season and for the total fire occurrence workload for all seasons simulated, as requested.

Each fire is assigned to one of seven or less damage classes representing dollar value per acre with a positive or negative dollar value for each class. Negative values are used when fire effects are benefits; positive values when damages.

Fixed costs consist of presuppression charges related to initial attack preparation, prevention, detection, and capital improvement depreciation. Variable costs in the FOCUS cost module consist of suppression charges, normal staffing, and unused contracts. The cost and losses from large fire gaming must be added manually to these summaries for overall totals.

The bottom lines of the seasonal or total workload summary report permit an overall cost-plus-loss amount to be derived. To date, this information has been interpreted in three ways: to compare one alternative to another on the basis of total cost-plus-loss (*table 5*), to compare alternatives to the costs and losses of the current base plan to derive differences from the base plan (*table 6*)—this will give the same results as the above—or to compare alternatives of equal incurred damages on the basis of economic efficiency or minimum cost.

In the comparison of cost-plus-loss, the lowest overall total would represent to some managers the best alternative. This traditional method of identifying the best decision usually requires a wide range of alternatives. During FOCUS testing, this comparative method was widely applied in evaluating alternatives. Most professional fire managers are wary of these results because the input damage potential resource values used to compute fire damages are regarded as unrealistic and oversimplified.

The comparison of current base plan costs and damages to other alternatives (*table 6*) is a form of

Table 6—*Differences in cost and loss for alternatives from base plan*

Plan	Cost (Millions of dollars)	Difference		Loss (Millions of dollars)	Difference	
		(Millions of dollars)	(Pct.)		(Millions of dollars)	(Pct.)
Base Plan:						
B	1.862	0	0	0.461	0	0
Alternatives:						
A	3.083	+ 1.221	+ 66	.153	− .308	− 67
C	1.031	− .831	− 45	.654	+ .193	+ 42
D	.625	− 1.237	− 66	.955	+ .494	+ 107
E	.740	− 1.122	− 60	.802	+ .341	+ 74

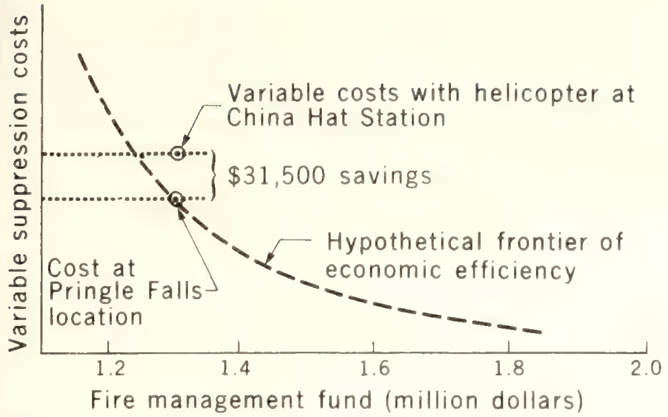

Figure 25— FOCUS can analyze variable cost savings. The Deschutes National Forest, in Oregon, compared the suppression costs of basing a helicopter at two different locations, with effectiveness kept constant for the two alternative locations.

benefit-cost analysis. Here, the loss (or benefit) difference can be compared with the cost (or savings) difference. This cost-effectiveness summary indicates where the biggest decreases can be made in damages per unit of additional cost or where the smallest increases in damage would result from given reductions in cost. This method has been attractive in those states where public cash-flow problems are of increased concern to legislators.

FOCUS cost output and diagnostic resource summaries can identify the most economic variable cost proposal (*fig. 25*). During a period of arbitrary funding constraints, an evaluation which emphasizes cost reduction due primarily to new technology becomes increasingly popular.

Experience has shown that during the operational testing phase those planning units which use a variety of the discussed analytical techniques also provide the best overall performance in developing new protection systems. A more indepth explanation, with examples, of how the various analytic techniques can be applied to evaluate FOCUS output is given by Flatman and Storey (1979).

A survey of FOCUS test planning units at the end of the operational test period listed the experienced costs (*table 7*, under planning costs). The average cost to implement a planning unit (salary, travel, per diem, computer, and overhead) is $34,000. Except for the Cleveland Unit, all managers stated that the historical fire planning process would cost as much or more than the costs experienced by using the new FOCUS system.

This limited sample reveals several apparent cost correlations. Very little relationship exists between the size of the fire problem (as represented by the fixed fire management fund) and planning costs. Planning costs apparently seem more dependent on organizational and overhead complexities. On the other hand, cost savings due to the use of FOCUS relate somewhat to the size of the fire workload and fire budget.

Table 7—*FOCUS first-time planning costs, organizational effort, and return*

National Forest	Planning costs	Fire management fund (78)	Technical efficiency savings (1st year)	Organizational effort[1]
	Thousands of dollars			
Francis Marion	34	367	0	Medium
Huron-Manistee	26	340	([2])	Low
Sawtooth	35	650	31	Medium
Clearwater	14	930	25	Low
Deschutes	35	1,330	189	High
Tonto	25	2,292	([3])	Medium
Cleveland	83	4,120	154	Very high
Average	34			

[1] A judgment based on relative size and expenditure of funds at regional and planning unit staff levels.

[2] Still testing.

[3] Not sampled.

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FOCUS (Fire Operational Characteristics Using Simulation) is a computer simulation model for evaluating alternative fire management plans. This final report provides a broad overview of the FOCUS system, describes two major modules—fire suppression and cost, explains the role in the system of gaming large fires, and outlines the support programs and ways of implementing the system.

Retrieval Terms: fire management planning, fire suppression cost, simulation, mathematical models, FOCUS (computer program)

United States
Department of
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Forest Service

**Pacific Southwest
Forest and Range
Experiment Station**

General Technical
Report PSW-50

Protecting Residences From Wildfires: a guide for homeowners, lawmakers, and planners

Howard E. Moore

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Protecting Residences From Wildfires: a guide for homeowners, lawmakers, and planners

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CONTENTS

Recommendations 1
Introduction 3
Nature of the Problem 5
  Residential Developments 5
  Fire Hazards and Risks 6
  Fire Suppression Difficulty, Costs, and Limitations 8
  Floods and Erosion 9
  Lack of Single Solution 10
Land-Use Planning and Zoning 11
  Fire Hazard Severity Classification 11
  General and Specific Plans 12
  Zoning Ordinances 12
  Spacing and Building Density 12
Property Development 14
  Access 14
  Water Supply 15
  Perimeter Protection and Fire Access 16
  Electric Power Distribution 17
  Street Names and Numbers 18
  Fire Station Sites 18
Structural Design and Construction 19
  Roofing 19
  Vents 20
  Overhangs and Stilt Construction 20
  Glass 21
  Siding 21
  External Sprinklers 22
  Safety of Human Life 22
  Mobile Homes 22
Landscaping 24
  Native Vegetation 25
  Plantings 25
  Irrigation and Sprinkling 26
  Herbicides 27
  Fire-Retardant Chemicals 27

Maintenance 28
  Roofs and Rain Gutters 28
  Yards 29
  Storage 29
Accessories 31
  Swimming Pools 31
  Fences 32
  Outbuildings 32
  Patios, Sun Decks, Balconies 32
  Water Pumps 33
  Fuel Tanks 33
Occupant Activities 34
  Advance Fire Protection 34
  Preparations for Possible Emergency 35
  Wildfire Approaching 35
Financial Incentives 36
  Insurance Surcharges 36
  Loan Terms 37
  Tax Adjustments 37
Undeveloped Areas: An Additional Problem 38
  Fuels Management 39
  Legislation 40
  Fire Defense Systems 41
  Fire Alert Systems 41
Literature Cited 42
Glossary 44

RECOMMENDATIONS

- Zone for its relative fire hazard severity all land, whether in a city or unincorporated area, that is not already developed for residential, commercial, industrial, or cultivated agricultural use, in addition to land-use or other zoning.
- Require by law that general and specific plans contain an evaluation of fire protection problems and a delineation of the means to cope with them.
- Require all cities and counties having any areas of undeveloped wildlands within their boundaries to review their ordinances on planning, land use, building, and fire for the purpose of making them truly effective in reducing the danger of destruction of residences and other structures by wildland fire.
- Impose standards of building spacing and density for wildfire hazardous areas by local ordinances. Base such standards on a classification system related to vegetative fuels, topography, and known weather patterns.
- Prior to development of any project intended for human occupancy in wildland areas—whether the development be conventional subdivision, planned unit, cluster, lot split, commercial, or industrial—provide two or more access routes adequate to allow two-way travel over roads that are not blocked by the fire or the results of the fire (e.g., fallen trees or powerlines, vehicle wrecks).
- Authorize permit-granting agencies to require developers, before they build any structures in wildlands, to provide adequate water supplies and the means of delivering them to protect such structures.
- Incorporate perimeter protection from wildland fires into the design of every new subdivision and mobile home park developed in wildland areas.
- Install electric power distribution circuits underground in wildland areas.
- Mark every road at each intersection and identify every land parcel or home in wildfire hazardous areas, in a manner clearly visible from a public road by names or numbers.
- Dedicate structural fire station sites before approving plans for any large, expensive, or high-occupant density development in a wildland area.
- Require all buildings located in wildfire hazardous areas to have roofs with a fire-retardancy commensurate with the hazard classification.
- Cover all exterior attic and underfloor vents with screens that are adequate to prevent the entrance of flammables and firebrands.
- Design all homes and other structures to be located in or near wildfire hazardous areas with as few overhangs and projections as possible and where they are unavoidable protect them from ignition through heat and flame entrapment.
- Design, orient, manufacture, and install all glazed openings, especially large picture windows and sliding glass doors, in a way that minimizes the opportunity for interior ignition from external sources.

- In all structures that may be exposed to danger from wildland conflagrations, construct the exterior walls using fire-resistant material commensurate with the degree of hazard involved.
- Do not install permanent roof sprinklers.
- Design and equip all structures—especially dwelling units—to provide occupants warning of a fire and ready escape routes.
- Design, build, and install mobile homes with the same regard for fire safety as used in any other residence.
- Clear and bottom-prune all native vegetation (except for isolated specimen plants) in chaparral and other wildland areas for a distance from each structure appropriate to the fire hazard severity class and slope class of the site.
- Plant and maintain with fire retardant or low-fuel-volume plants all areas cleared of native vegetation for fire protection purposes, if such areas are not maintained free of flammables (e.g., paved areas).
- Irrigate landscaping plants at least until they become well established, but do not irrigate native vegetation.
- Consider the use of selective herbicides to achieve specific purposes in fire protection landscaping to be both desirable and legitimate.
- Explore the feasibility and economics of fire-retardant chemicals used on surrounding vegetation, native or planted, for home fire protection in wildfire hazardous areas.
- Maintain roofs in a fire safe manner (i.e., clean and made of fire-retardant materials).
- Maintain all yards, gardens, landscaped areas, and fire protection clearances so as to retain their fire safe qualities.
- Do not store uncovered flammable materials against the exterior wall of any building nor close enough to it to cause ignition of the structure by radiated or convective heat should the materials burn.
- Install and equip every swimming pool or other significant water source in wildfire hazardous areas such that the water may be obtained quickly and easily for firefighting purposes both by fire engines and by the occupant.
- Design, construct, and maintain fences so that they do not help wildland fires spread—especially to structures.
- Build and maintain outbuildings to the same standards of fire safety as the residence or other main structure with which they are associated.
- Design and install patios, sun decks, and balconies in ways that enhance the fire safety of the building to which they are an accessory.
- Install private water systems in a way to provide adequate, dependable source of water for fire protection purposes.
- Install storage tanks for hydrocarbon fuels so that they are separated from native vegetation by the same distance required for the residence, provided with a nonflammable heat shield, and separated from other structures by the same distance required for structures.
- Prepare and test a plan for protecting property from fire and have on hand the tools and equipment needed for such an emergency.
- Take special precautionary measures to protect property from fire during very high and extreme fire weather conditions, whether an actual fire is in progress or not.
- When a wildfire becomes a threat to a home or other structure in or near wildlands the occupants should take final protective actions and evacuate all who cannot make a positive contribution to a firefighting effort.
- Establish fire insurance rates for structures located in or near wildfire hazardous areas to reflect the actual probability of destruction by conflagration.
- Adjust the interest rates and other conditions for all real estate or development loans in hazardous wildfire areas so as to encourage fire-safe design and construction.
- Provide tax incentives to persons who meet or exceed minimum fire-safe standards, and apply tax penalties to those who fail to conform to standards.
- Treat and continuously manage vegetation fuels on all wildlands that may become fire threats so as to reduce the conflagration hazard and facilitate fire control.
- Encourage the legislative bodies of states, counties, and cities to conduct a critical review of their laws and regulations relating to wildland fire protection and, on the basis of such reviews, adopt new measures that will provide reasonable fire safety and resolve conflicts of law with other public safety and environmental protection measures.
- Establish fire defense systems in advance on all undeveloped wildlands so located as to pose a fire threat to areas developed for human use and occupancy.
- Enlist the aid of property owners and others with vested interests in homes and other structures located in or near wildland areas, both as individuals and through their organizations and associations, in seeking ways to participate in and improve the Red Flag Fire Alert System.

Each year, wildfires burn hundreds of homes and other structures in or adjacent to forests and rangelands. And even before the last flames have flickered out, some owners begin thinking about rebuilding homes on the very sites scorched by fire. This situation is not new or confined to a particular area; nor are the proposed remedies new or applicable only to a particular area.

Southern California epitomizes the problem of protecting homes from recurring wildfires. Several conditions contribute to a fire protection problem that is as severe as to be found anywhere. Vegetation, ranging from heavy stands of grass to brush to hardwoods or conifers, thrives in the Mediterranean climate there. Other conditions contributing to the high fire hazard are the large population, mountainous topography, and an increasingly affluent, mobile society encroaching into wildlands.

These same conditions are found in other regions that enjoy the Mediterranean climate—parts of Europe, Australia, Chile, and South Africa. The vegetation produced and the resulting fire protection problem are not greatly different from those found in California.

Much has been written about what can be done to remedy the problem, but few recommendations have been implemented. Many studies merely duplicate work done previously. To bring all of the pertinent information together, I reviewed the extensive literature on fire protection, and made personal contacts to obtain or confirm sources or both.

This report summarizes information on procedures for reducing losses of residences and other structures from wildfires. It outlines the problem of protecting homes from such fires, and proposes recommendations and standards. The Proposed Standards are proposals for the technically best solutions. Worded in advisory language, these standards must be reworded into mandatory language when enacted into laws, ordinances, or other requirements.

The findings in this report apply not only to residences but to commercial, industrial, and recreational developments. Many building and fire codes now require fire-resistant construction for such developments. Few codes, however, address the problem of wind-driven fires crossing broad expanses of wildland fuels.

Responsibility for fire protection cannot be relegated to a single element of society. It calls for the combined efforts of government agencies and the private sector (*fig. 1*). More than anything else, it requires the concerted efforts of homeowners and occupants. This guide is designed to help owners, occupants, lawmakers, planners, architects, builders, bankers, insurers, and financiers meet that responsibility.

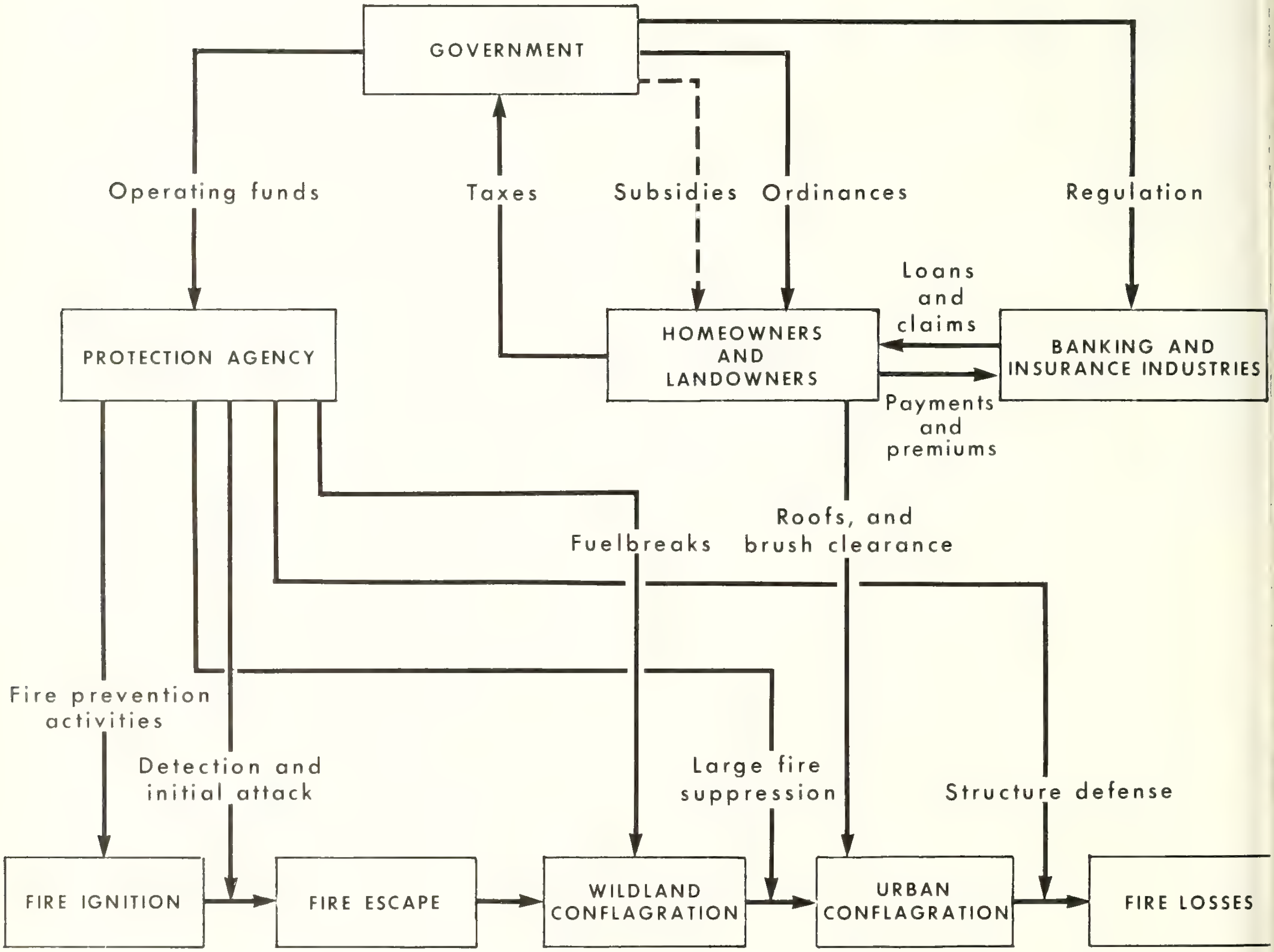

Figure 1—Parties in wildland fire protection include government agencies, homeowners, landowners, and industry. The protection process at the urban/wildland interface includes fire prevention, fire suppression, and structure defense (Howard and others 1973).

NATURE OF THE PROBLEM

Residential Developments

Because of the congestion and pollution of major metropolitan areas, subdivisions, individual homes, and mobile home parks continue to proliferate year after year. Many are in or close to wildland fuels, subjecting them to the danger of being burned (Harvey 1974; Hulbert 1972; Orange County Bd. Sup. 1976; Oreg. St. Dep. For. 1978a). This development has usually proceeded faster than has the enactment of effective laws and ordinances to alleviate the problem. Because of financial, social and political pressures, even those efforts previously made to require firesafe construction and occupancy have been only partially enforced, and, therefore largely ineffective (Hulburt 1972).

Within commuting distance (40 to 60 miles) of metropolitan areas, development most often takes the form of relatively expensive residences on medium-to-large lots. Unless prohibited by well designed and effectively enforced ordinances, developers tend to leave as much native vegetation as possible to maintain and promote the rural effect that the buyers seek. Similarly, developers usually provide wood shingle or shake roofs, picture windows, and sun decks. Water and other utilities are usually provided only in amounts adequate for normal use unless fire codes are strictly enforced. Because of high land values, road rights-of-way tend to be narrow and, if in mountainous areas, steep. In such circumstances, residents often have only one route of ingress and egress (Orange County Bd. Sup. 1976; Los Angeles County 1973).

In addition to suburban subdivisions, hundreds of thousands of residences and their outbuildings have been built in the past few years beyond practical commuting range from cities. Such buildings can be found in any of several arrangements. One is the rural subdivision composed of second (weekend or vacation) and/or retirement homes. Except for location and the inclusion of some recreation and light commercial development, these subdivisions appear similar and present fire problems similar to those posed by suburban subdivisions.

Although fewer than those in subdivisions, the structures that individually cause the greatest fire protection problems are ones built by or for their occupants on individual parcels of land, each usually with its own water system. The most dangerous of these problems result from so-called lot splitting. Lot splits tend to create densities approaching those of subdivisions without any of the inherent advantages of subdivisions (e.g., access to a public thoroughfare, water system, refuse disposal, sewage system). All individually developed residences, whether on large farms or small parcels of land, are difficult to protect from fire. Their water supply is seldom adequate. Access is usually long, narrow, and slow. Electric power, if available, is subject to interruption, often by the fire itself.

A relatively new structural fire problem is the mobile home, which presents all the fire problems of the conventional home and several more. Because the structure itself is more susceptible to flash fire, occupants find it more difficult to escape. If the structure is not fitted with adequate skirting, wildfire will run quickly under

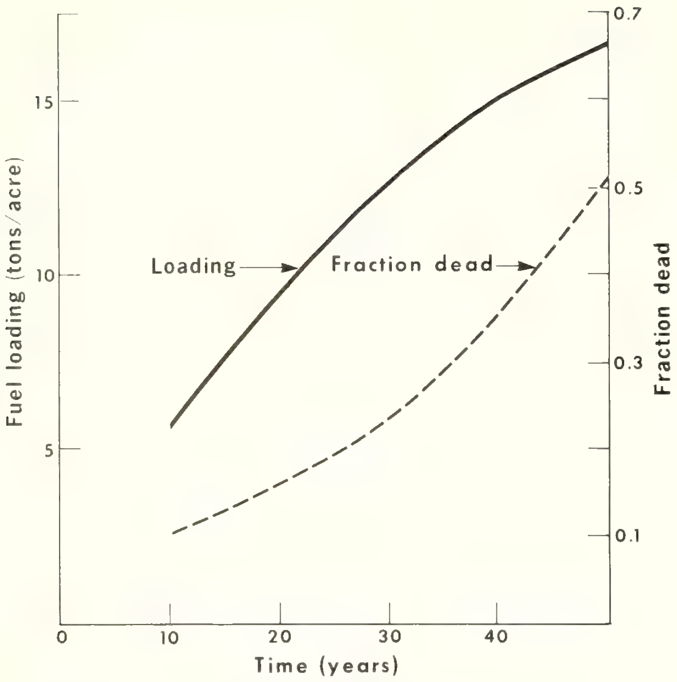

Figure 2 — Total fuel loading and fraction of dead material both increase as chamise ages (Philpot 1974).

the floor. A mobile home is easier than a conventional house to set up with little or no clearing of native vegetation. And when it is placed in a mobile home park, the spacing between structures normally is insufficient to prevent a fire from spreading by radiation or convection (Los Angeles County Fire Dep. 1970; Org. St. Dep. For. 1978a).

Fire Hazards and Risks

Fire hazards are those elements in the combustion process that actually burn or that cause the fire to burn faster or hotter than normal. Fire risks are those factors that cause fires to be ignited. To protect residences and other structures from damage by wildland fire, both fire hazards and fire risks must be understood and dealt with. Fire hazards fall into three broad categories: fuels, weather, and topography. Fuels, in turn, are composed of two types: vegetation and structures.

Composed of cellulosic materials, all vegetation is flammable to some degree. Some types (e.g., chaparral) are much more flammable than others (e.g., irrigated landscaping plants). All vegetation is more flammable at certain times than at others. Vegetation in its wild state consists of both living and dead materials. The dead materials and the fine living materials (leaves or needles and twigs) represent the bulk of the "available" wildland fuel. *Figure 2* shows how fuels increase with time. In timber stands and heavy brush fields, this available fuel may reach 50 tons per acre. In areas of 1- to 2-year-old logging slash, fuel loading may run up to 200 tons per acre. When hundreds or thousands of acres of such volumes of fuel are burned in short periods of time—as often happens under conflagration conditions—the amount of heat and energy released approaches that of an atomic bomb. Flame lengths can exceed 100 feet. Radiated heat can ignite exposed flammable materials at distances of 100 or more feet. Convection columns carrying flaming leaves and other fire brands often extend many thousands of feet into the atmosphere and have been known to drop such firebrands several miles downwind. Thousands of homes can be exposed to these conditions (Task Force on California's Wildland Fire Probl. 1972, Helm and others 1973, Nord and Countryman 1972).

Of particular concern is the wildland fuel known as chaparral, because so much of it is in or near metropolitan areas. Chaparral also represents an unusually dangerous fire hazard because of its inherent qualities. As a "fire climax plant community," chaparral has for thousands of years not only survived repeated fires but has adapted itself to depend on fire for regeneration and survival. Thus wherever chaparral exists large-scale fire can be predicted with great certainty to occur sooner or later, and the longer between fires the larger they are (*fig. 3*). In southern California, the average time between fires in any given area (cycle time) is about 30 years (Hanes 1974, Nord and Countryman 1972, Philpot 1974, Wright 1972).

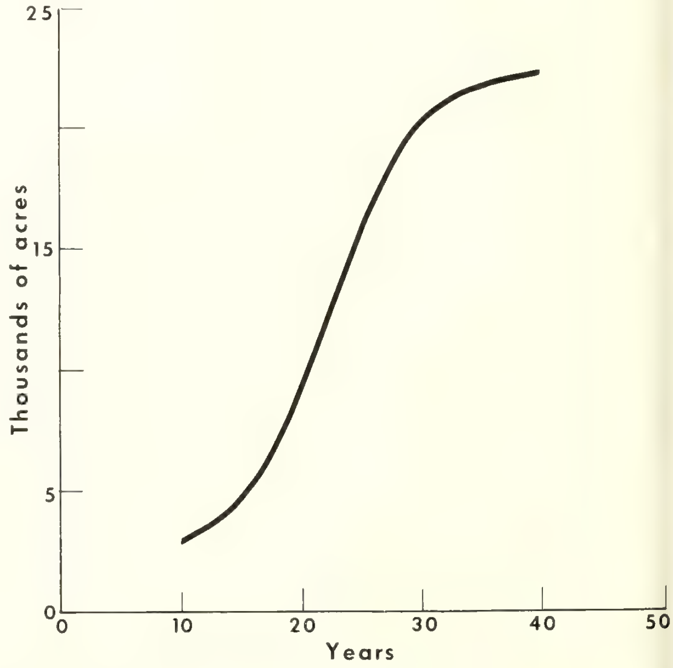

Figure 3 — A wildfire increases in size as the age of chamise increases (Philpot 1974).

Structures built in wildlands can also be hazardous fuel. They are mostly of wood frame construction, often with wood siding. Wood shingle or shake roofs are common, particularly in suburban and rural subdivisions. Attic and floor vents are often left unscreened. Picture windows and stilt or cantilever balconies facing directly into or over heavy wildland fuels are common. Many roofs and rain gutters hold large quantities of dry leaves or needles. Dooryards often are not kept clear of flammable vegetation. Any or all of these qualities contribute to make these structures one of the most hazardous fuels in the urban, suburban, rural or wildland setting (Alger 1971, Task Force on California's Wildland Fire Probl. 1972).

Weather, or more specifically "fire weather," can properly be termed a fire hazard because it aids ignition and accelerates combustion. Almost all conflagrations have occurred during periods of extreme fire weather. We can do little about the weather except to understand it and its interactions with the other hazards. Yet weather is at least as important as fuels in the urban/wildland interface fire problem.

The weather elements responsible for very high or extreme fire danger are strong winds, high temperatures, low humidities, and low fuel moisture contents. This combination can happen, and has, at almost any time of the year, including the middle of winter. In areas with Mediterranean climates, such as most of California, extreme fire weather is actually quite common during late summer and fall, and should be expected to be present one or more times at any point in the State during the period from mid-June to mid-November (Alger 1971, Task Force on California's Wildland Fire Probl. 1972, Deeming and others 1977, Phillips 1971).

By far the most critical factor in fire weather is wind. A study of fires 5000 acres or larger during the period 1961–70 revealed that at the time of start of 66 fires for which weather records were available, the average wind speed was about 30 mph; in some it went as high as 75 mph (Los Angeles County Fire Dep. 1970, Task Force on California's Wildland Fire Probl. 1972).

Table 1—*Santa Ana frequency and duration by month in southern California, 1951–60*

Month	Frequency	Average duration (days)
September	11	4.4
October	19	4.5
November	26	5.0
December	18	3.7
January	7	1.7
February	10	1.9
March	17	2.5
April	8	1.8
May	7	1.4
June	4	4.5
July	2	2.5
August	0	0

Source: Countryman (1974).

The most dangerous wind is the foehn (subsidence) wind, the most notorious being the Santa Ana of southern California (*table 1*). In other parts of the world this wind is known by other local names, such as mono, north wind, mistral, chinook, tramontana, and williwa. The foehn wind produces the usual effects of winds: fanning and supplying oxygen, preheating fuels by bending flames from the vertical, and carrying burning firebrands ahead of the fire front. But it also brings dry air from continental high pressure areas, then heats and dries it further by compression as it flows to lower elevations at a velocity of up to 100 mph (Alger 1971, Orange County Bd. Sup. 1976, Task Force on California's Wildland Fire Probl. 1972, Phillips 1971).

High temperatures bring the fuels, both vegetative and structural, closer to their ignition temperatures. Low humidities dry the moisture from the fuels. Low fuel moistures, by reducing the amount of heat used in vaporizing moisture, reduce the total amount of heat needed to raise the fuel to ignition temperature. Even green fuels, particularly chaparral, can have remarkably low moisture contents after long dry summers or under adverse fire weather conditions (Deeming and others 1977, Hanes 1974, Nord and Countryman 1972, Philpot 1974, Wright 1972).

The third major hazard contributing to wildland and structural fire danger is mountainous topography. Although it increases the costs of construction and development, such topography attracts thousands of homeowners with its feeling of openness, an attractive view, and the possibility of getting above or away from the smog. Sidehill construction often makes structures more ignitable (e.g., stilts, cantilevers). Topography affects fires in some of the same ways that wind does as well as modifying, and often intensifying, the effects of the wind. Generally fires run faster uphill than down. Higher elevation fuels (e.g., houses on ridgetops) are preheated by flames and convection columns even in the absence of wind. Canyons act as chimneys trapping heat and intensifying combustion. Canyons, saddles and ridgelines deflect, and often intensify, winds. Thus the mouths of canyons on the lee side of main ridges often become raging infernos during a Santa Ana. Roadbuilding is difficult and expensive in mountainous terrain, often making ingress for firefighting manpower and equipment and egress for residents slow and difficult.[1]

The fire risks involved in the structural/wildland fire problem are almost all man-caused. In the populated portions of California, 90 percent or more of the fires involving vegetation are caused either by people directly or by their developments (e.g., arson, various types of machines, power lines); only 4.2 percent of the conflagration fires are caused by lightning. The mere acts of developing, constructing and occupying structures in formerly wildland areas, therefore, expose both the wildlands and the structures to increased risk of destruction by fire (Alger 1971, Task Force on California's Wildland Fire Probl. 1972, Moore 1977).

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[1] Alger 1971, Task Force on California's Wildland Fire Probl. 1972, Deeming and others 1977, Hanes 1974, Helm and others 1973, Los Angeles County Fire Dep. 1970, Orange County Bd. Sup. 1976, Philpot 1974.

The risk of structural ignition during wildland fires comes from any of three sources: direct exposure to flame, radiated heat, or firebrands carried by winds or convection columns or both. The first two of these sources can be fairly easily guarded against by proper clearance of native vegetation, landscaping, and maintenance. The last (most common) is much more complex and requires a combination of defenses, including all those described in the chapters on Land-Use Planning and Zoning; Property Development; Structural Design and Construction; Maintenance; and Undeveloped Areas. The most usual structural fuel bed for ignition by these flying firebrands, which are often carried from one-quarter mile to 2 miles ahead of the fire front, is the roof. Therefore, roofing materials and cleanliness are of prime importance as protective measures (Alger 1971, Los Angeles County Fire Dep. 1970, Orange County Bd. Sup. 1976, Task Force on California's Wildland Fire Probl. 1972, Helm and others 1973).

Fire Suppression Difficulty, Costs, and Limitations

The owners of structures in or near wildland fuels cannot depend on the fire suppression efforts of public agencies to protect their buildings from destruction. The use of tax funds to pay for enough firefighters and equipment to contain every fire that starts on the few days of very high and extreme fire weather conditions is both economically and politically infeasible. It is, in fact, also physically impossible under typical conflagration conditions of very strong, hot, dry winds. Therefore, each owner or resident must assume his or her share of the responsibility for preventive measures (Alger 1971, Los Angeles City-County Fire Bd. Inquiry 1971, Green 1977, Howard and others 1973).

Firefighting is at best one of the most hazardous activities of man. Under conflagration conditions, the risks of entrapment, asphyxiation, heat exhaustion, falling, and other injuries become so great that chief officers and other leaders will usually not allow their men to be at the head of the fire. Also under these conditions smoke and air turbulence often preclude the use of air tankers or helicopters. The only effective perimeter control, therefore, is on the flanks of the fire until it reaches some barrier or the weather changes (Los Angeles County Fire Dep. 1970, Los Angeles City-County Fire Bd. Inquiry 1971, Howard and other 1973).

The strategy of wildland fire control requires perimeter control, containment of spread, and eventual extinguishment. Due to the scarcity of water, the tactics of wildland fire control usually consist of constructing fire lines, either by hand or with machines, burning out prepared or preexisting control lines, cooling limited areas by air drops of fire retardants, and similar measures. Such work cannot be carried out safely or effectively on steep hillsides or in close proximity to a high intensity fire in heavy fuels. It must usually be done at some natural or artificial barrier, e.g., a ridgetop or interstate freeway. If the wind is very strong, even these barriers often will not hold because of spot fires caused by flying firebrands (Alger 1971, Los Angeles County Fire Dep. 1970, Los Angeles City-County Bd. Inquiry 1971, Howard and others 1973). Consequently wildland fire control is basically incompatible with the aim of protecting structures.

Most wildland fire protection agencies consider their primary statutory mission to be resource protection, and have budgeted accordingly. In spite of this limitation, wildland firefighters normally react to human moral values when faced with a choice of either saving life or improved property, or saving several hundred acres of brush or timber. Therefore, even though their equipment and training are often poorly designed for structural firefighting and adequate water is usually lacking, firefighters tend to let the fire spread while they do the best they can to save lives and structures (Alger 1971, Los Angeles County Fire Dep. 1970, Oreg. St. Dep. For. 1978b).

Mountainous terrain complicates fire suppression in several ways. The combined effects often make it impossible to save houses from burning during major wildland conflagrations, and, as discussed earlier, steep slopes, canyons and ridges complicate and intensify the effects of wind. Even in the absence of wind, fires race much faster up a steep slope than they do on the level. It is difficult, slow and dangerous to fight fire on steep, rocky side hills. The combined effects of terrain and wind often create smoke and air turbulence conditions which preclude the use of aircraft. Mountain roads make access and response time slow and difficult for firefighters and for heavy fire trucks and other equipment. Sometimes access becomes impossible when roads are blocked by debris, other vehicles, or the fire itself or if construction of the roads themselves has made them too steep or with curves too tight to be traversed by fire engines or bulldozer transports (Alger 1971, Los Angeles County Fire Dep. 1970, Green 1977, Howard and others 1973).

The control of major wildland fires, usually involving structures, is further complicated by the communication and coordination problems inherent when the fire is being fought by multiple agencies, which is usual for two reasons. First, wildland fires do not respect political, jurisdictional, administrative, or ownership boundaries. A fire of any appreciable size will usually spread from the protection jurisdiction of one agency to those of several other agencies. Secondly, no single agency, even the largest, has the resources to handle a major conflagration alone. Aid from other agencies, often from considerable distance, must be called in. As a result, differences in training, equipment, and radio channels regularly exist. The effects of these differences are usually minimized before a fire through joint planning and coordination between adjoining agencies. But if agencies are responding from a distance in emergency situations, coordination of the efforts can be a serious problem (Alger 1971, Los Angeles County Fire Dep. 1970, Los Angeles City-County Fire Bd. Inquiry 1971, Oreg. St. Dep. For. 1978b, Lowden and Degenkolb 1972).

The fire protection available to structures in mountainous areas in or near rural or wildland fuels is often limited in certain other ways not usual for similar structures located in cities. Federal and State wildland fire protection agencies are funded only during the wildland fire season. At other times of the year, manpower is sharply reduced, outlying stations are closed, and 24-hour service is terminated. In some areas, a local agency (county or fire district) can make up this deficiency by entering into a contract with the State for firefighting services. Other areas receive structural protection from low-budget volunteer fire departments funded by counties, fire districts, or informal donations from private citizens. Their equipment may be old, training inadequate, and response time excessive. Even when professionally manned and well equipped, county or district fire departments generally have longer response times than do city departments and water is not as easily available. Thus the fire protection for structures in rural and wildland areas is at a somewhat lower standard (Alger 1971, Oreg. St. Dep. For. 1978b).

Floods and Erosion

Burning is not the only way in which a residence may be damaged or destroyed by wildland conflagration. A fire, particularly a large one, anywhere upslope from the structure is likely to produce flood or erosion damage or both when the next rains come. For houses near the bottoms or mouths of canyons or those perched on or directly under very steep slopes or fills, this danger may be even greater than that of direct fire damage. Of course, the opposite is true of structures located on ridges or high on slopes.[2]

That hillside soil bared to the elements by fire is susceptible to accelerated erosion is rather self-evident and has been noted by many researchers and fire officials. What is not so widely known is that many soil types are made hydrophobic (water-repellent) by fire. The overland flow of water during rainstorms is increased by 10 to 40 times the normal (unburned) amount because of this phenomenon. This tremendously accelerated runoff not only creates high flood waters, but provides the force needed to move soil, gravel, and boulders

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[2] Calif. Reg., For. Serv. 1971; County Sup. Assoc. Calif. 1966; Houts 1974; Los Angeles County 1973; Los Angeles County Fire Dep. 1970; Rice 1974; Stallings 1970; Zivnuska 1974.

downslope and downstream and to transport channel deposits accumulated largely by dry erosion between fires (Houts 1974, Rice 1974, Zivnuska 1974).

Lack of Single Solution

No single solution to the fire protection problem can be proposed. Because so many hazards, risks and complicating factors are involved, a combination of remedies is required to achieve any reasonable degree of fire safety for structures in or near wildland areas. Some of the potential problems should be solved long before any structures are built. Other corrective measures should be adopted during the development and construction phases. Still others must be practiced continuously or intermittently so long as the structure remains in existence.

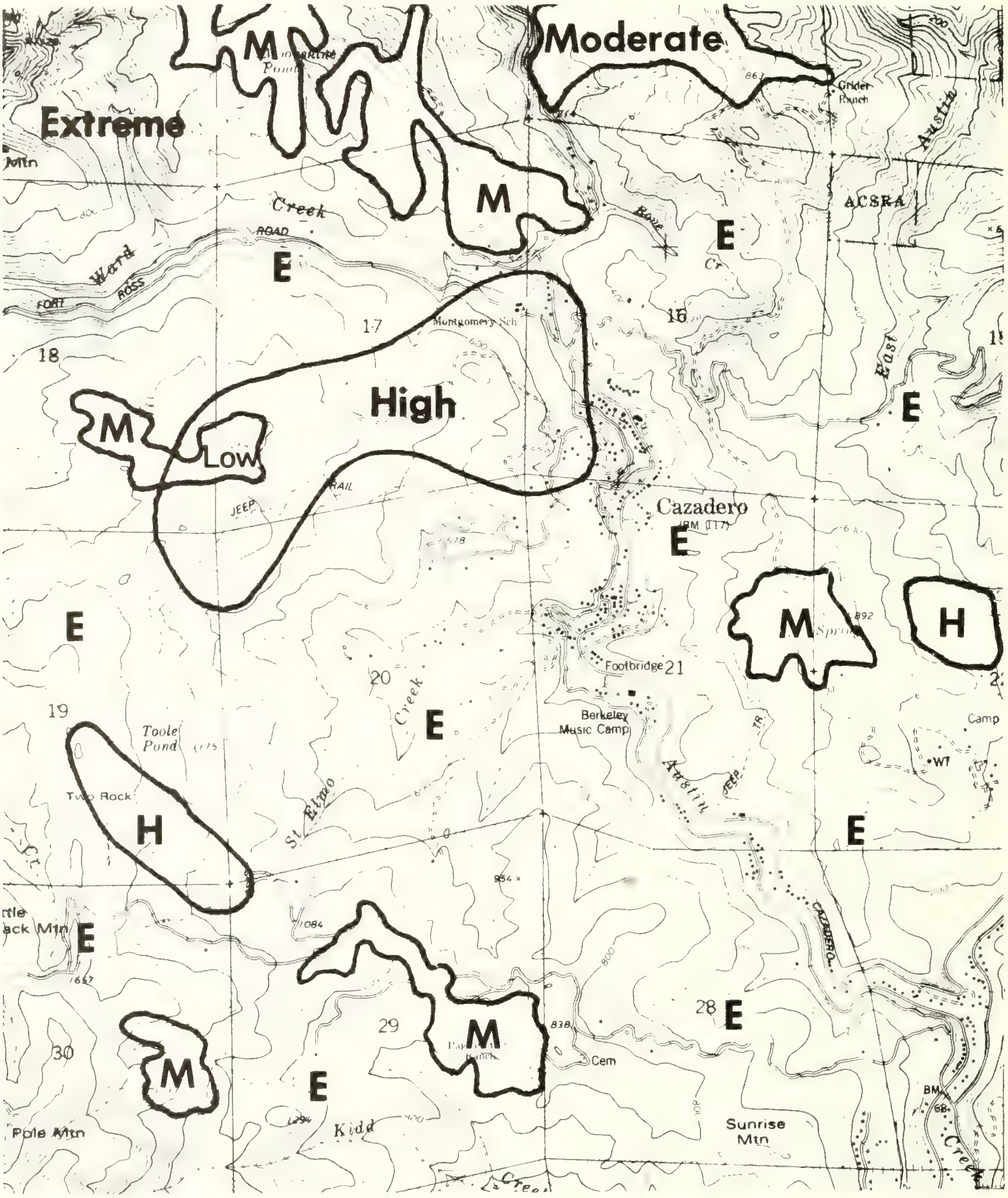

Figure 4—The severity of fire hazard in an area can be classified and mapped.

LAND-USE PLANNING AND ZONING

Land-use planning and zoning are governmental functions critical to public safety—including fire protection. But because these functions are political as well, they are subject to intense differences of opinion and to public controversy. Therefore, they tend to lag behind development until the problem becomes aggravated, much in the fashion of the traffic light that is installed only after eight or ten deaths have occurred at the intersection. Being political they are also subject, even after enactment into law, to pressures for variances and modifications. Therefore, they are seldom as effective as fire protection personnel would like to see them. With few exceptions, they cannot be made retroactive and, consequently, older developments are not much affected by them. Where land-use planning and zoning have been enforced, however, they have achieved significant degrees of fire safety (Oreg. St. Dep. For. 1978b, San Bernardino County Bd. Sup. 1974).

Fire Hazard Severity Classification

Fire hazards are relative and range from the base level hazard found in any urban area to the extreme hazard found amid heavy chaparral on a steep side hill in an area where extreme fire weather commonly occurs (*fig. 4*), such as southern California. Some counties where the problem was recognized early (as long as 40 years ago) have taken the simplistic in-or-out approach to wildland fire hazard zoning. Those which have entered the field recently (in the past 5 years) have tended to employ two or three hazard levels in their zoning (Orange County Bd. Sup. 1976, Los Angeles County 1937, San Bernardino County Bd. Sup. 1974, Helm and others 1973).

Probably the best approach to fire hazard classification or zoning from the standpoints of both technically correct theory and practical application by local planning department staffs is that developed in 1973 by the California Department of Forestry. It rates fire hazard based on three weighted values each of fuels, weather, and topography (*table 2*). In light of more recent information (Deeming and others 1977) the limits and factor weights may be revised, and whether a "low" or "base level" fire hazard classification should be recognized at the lowest levels of all factors in the table should be explored. Still the factors used and the approach to combining and analyzing them are sound. Technically it might be more correct to use up to 20 fuel types and five slope classes as recognized by the National Fire Danger Rating System (Deeming and others 1977) but this would unnecessarily complicate analysis and mapping.

In any event, this system or a modification of it can identify those areas which present varying degrees of fire hazard, including those so hazardous that no construction or development should be allowed. It can also indicate which areas can be made reasonably safe through the application of various levels of design, construction, and maintenance standards (Orange County Bd. Sup. 1976, Task Force on California's Wildland Fire Probl. 1972, San Bernardino County Bd. Sup. 1974, Helm and others 1973).

Any such system should provide for raising to the next higher level of hazard those limited areas that are in saddles above canyons on the windward side of ridges or at the mouths of canyons on the lee side of main ridges (Los Angeles County Fire Dep. 1970).

Proposed Standards: Establish fire hazard severity zones on the basis of a graded classification system using fuel loading, fire weather, and slope as primary factors. Recognize and map at least two, but preferably three, levels of hazard. Provide for classification in the next higher category of especially hazardous situations, such as saddles on ridges above windward canyons and mouths of lee canyons.

Table 2—*Fire hazard rated on three weighted values of weather, fuels, and topography in California wildlands*[1]

Critical fire weather frequency	I			II			III		
	Slope (pct.)			Slope (pct.)			Slope (pct.)		
Fuel loading:	0–40	41–60	61+	0–40	41–60	61+	0–40	41–60	61+
Light (grass)	M	M	M	M	M	M	M	M	H
Medium (scrub)	M	M	H	H	H	H	E	E	E
Heavy (woods-brushwood)	H	H	H	H	E	E	E	E	E

Source: Helm and others (1973).

[1] M = moderate hazard, H = high hazard, E = extreme hazard.

General and Specific Plans

In dealing with wildfire, county or city plans vary greatly between one local government and another. Some plans merely recognize the fact that a fire problem may exist; other plans provide a detailed exposition of the nature and extent of the problem and a timetable for coping with it. General plans are prepared by the planning staff and approved by the planning commission and the governing body of a political subdivision of the State, i.e., county or city. They generally include Land Use, Transportation, Public Safety (which includes fire), and other elements designed to promote orderly growth and development. In California, some elements are mandatory and others optional by State law. One mandatory element is Public Safety, but in the past, there have been no standards to which this element had to be prepared[3] (Orange County Bd. Sup. 1976, Oreg. St. Dep. For. 1978b, County Sup. Assoc. Calif. 1966, Task Force on California's Wildland Fire Probl. 1972, San Bernadino County Bd. Sup. 1974).

Proposed Standards: Require that fire protection elements of general and specific plans cover both basic structural protection and protection from wildland fire, that protective measures enumerated in these plans correspond to the level of fire hazard severity found to exist in the area covered by each plan, and that the fire department participate in reviewing plans.

Zoning Ordinances

General plans and the various uniform codes (building, fire, etc.) have no force or effect until adopted by ordinances of local governing bodies (e.g., county boards of supervisors, city councils, fire district boards of directors) and provided with penalty sections (Task Force on California's Wildland Fire Probl. 1972).

In California, general plans including safety elements are mandated to counties and cities by State law (California Government Code Sect. 65300 et seq.). The standards set by the State to which these plans and elements must be prepared, especially those having to do with wildland fire, have been very weak. Consequently, an almost total lack of uniformity exists from one local jurisdiction to another. The governmental units that are larger, most heavily damaged in the past, and more progressive have adopted enabling ordinances containing rather comprehensive requirements relating to fire safety. In contrast, some of the smaller units and those that have not perceived or understood the severity of the problem have treated it in one sentence or one paragraph (Task Force on California's Wildland Fire Probl. 1972).

One important element of the General Plan is the Land-Use Element. It establishes the areas that can be devoted to different uses (e.g., residential, commercial, manufacturing, agriculture, open space). This element has great potential for enhancing structural fire safety in wildland areas if wildland fire hazard severity classes are accounted for during its development. So far this potential has rarely been considered, and no case has been found where the Land-Use Element of the General Plan was actually implemented in this manner.[3]

The Uniform Building Code (UBC) published by the International Conference of Building Officials has been adopted by many counties and cities. Others have no such code or ordinance. A major component of the UBC is the establishment of Fire Zones I, II, III. These zones set standards by requiring decreasing degrees of fire safety to be built into structures of various types of occupancy and prohibit certain occupancies in Zones I and II. Zone III generally encompasses residential areas having the lowest (base level) fire danger and requires minimal fire safety construction. In all zones, the standards are designed to provide protection from fires starting within the building or in another one nearby (3 to 20 feet). The problem of fires approaching through large expanses of vegetation is not addressed anywhere in the UBC (Task Force on California's Wildland Fire Probl. 1972, Int. Conf. Build. Off. 1976).

A few jurisdictions that have adopted the UBC by reference in an ordinance have amended it in various ways to attempt to cover the wildland fire problem. Some have added fire zones and incorporated certain restrictions and requirements for structures located in them. Others have declared fire hazardous wildland areas to be in Fire Zone II. In most cases the only effective remedial measure is the requirement of fire-resistive roofing (Build. News, Inc. 1977, County Sup. Assoc. Calif. 1966, San Bernardino County Bd. Sup. 1974).

Proposed Standards: Recognize varying degrees of wildland fire hazard in local ordinances. Establish construction and spacing standards commensurate with each degree, and make such standards applicable to residences and their appurtenant structures as well as to other types of occupancy.

Spacing and Building Density

To provide a reasonable degree of fire safety, building spacing and density must be different in mountainous areas, wildlands, and rural areas than they are in urban areas. This differentiation is needed because the usual source of ignition of the structure in the wildland or rural setting is external while in the more developed city situation it is internal. Exceptions to this general rule do occur, but they are relatively rare (Alger 1971, Los Angeles City-County Fire Bd. Inquiry 1971).

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[3] Hastings, John H. 1977. Fire safety guides for wildland planners. (Unpublished report on file, Region V, California Department of Forestry, Monterey, Calif.)

The Uniform Building Code (UBC), Uniform Fire Code (UFC), and most subdivision codes are based on two assumptions: an internal ignition and a fire department response time of less than 15 minutes. These are relatively safe assumptions in most cities and some fire districts, but are valid only in very limited areas where fire protection is provided by a county, State, or Federal agency. They are almost totally irrelevant in most mountain and wildland areas where only seasonal resource fire protection is usually available (Alger 1971).

In addition to being subject to external ignition and up to 2-hour response times, structures built on sloping ground are affected by the same fire behavior phenomenon discussed earlier in relation to the wildland fuel. The slope creates an effect similar to that of wind and causes fire to spread faster uphill than downhill or on the level. Buildings situated on slopes should be required, therefore, to be spaced farther apart than similar buildings built on essentially level ground. On excessively steep slopes (more than 55 percent), all wood frame construction probably should be prohibited[3] (Los Angeles County Fire Dep. 1970, Oreg. St. Dep. For. 1978b, County Sup. Assoc. Calif. 1966, San Bernadino County Bd. Sup. 1974, Helm and others 1973).

In recent years a new concept in residential development has been adopted in some areas. This is the cluster development in which the population density limitations of general land-use plans are met by placing individual homes or multifamily residences (e.g., duplexes, apartments, condominiums) in small groups on smaller lots than would otherwise be required. The land area thus saved is reserved for community open space. This practice is esthetically pleasing to most people, and can also improve the fire safety in rural or wildland areas as long as certain minimum spacing standards are followed. The space between buildings, for instance, should not be less than half that required between residences in conventional subdivisions in similar areas. And the native vegetation should be modified at least to fuelbreak standards of width and hazard reduction in the spaces between clusters (Task Force on California's Wildland Fire Probl. 1972, Colo. St. For. Serv. 1977).

Because of the close spacing commonly employed in mobile home parks, those situated in wildland fire hazardous areas are particularly susceptible to destruction or serious damage from conflagrations. Required spacing between mobile homes in such parks should be no less than that allowed between buildings in a cluster development in a similar fire hazard classification zone (Los Angeles County Fire Dep. 1970).

Most of the references on structure density and spacing base their recommendations primarily on slope. Only rarely are the other primary factors contributing to wildland conflagrations (i.e., fuels and weather) mentioned, mostly in work done in the late 1970's. The most logical and defensible standard on which to base structure density and spacing requirements is fire hazard severity classification and mapping (Colo. St. For. Serv. 1977, Helm and others 1973).

Proposed Standards: Establish minimum standards of building spacing and density, as shown below. Provide for the imposition of higher standards or the prohibition of building where local conditions (e.g., excessively steep slopes, ridge saddles, canyon mouths) create critical fire hazards:

	Individual buildings			Clusters	
Hazard class:	Density	Spacing	Prop. line setback	Between bldgs.	Between clusters
			Feet		
Moderate	3 per acre	60	30	30	100
High	1 per acre	80	40	40	150
Extreme	1 per 4-5 acres	100	50	50	200

PROPERTY DEVELOPMENT

Only the developer of a property can provide some of the vital means of fire protection, such as access and water supply. It is the developer's responsibility to know about them, and to design them into the project before any structures are erected. But others have related responsibilities. Planning departments should develop and legislative bodies should adopt minimum standards. Planning departments, with advice and assistance from operating departments (e.g., fire, public works, sanitation), should enforce the standards even if they must deny approval of nonconforming proposals. People with financial interests (e.g., bankers, insurers) should satisfy themselves that firesafe features are incorporated in the project before committing their resources. All development plans should employ the master planning concept in order to properly assess the interactions between various elements (e.g., public safety, transportation, sanitation, water, schools).[3,4]

Access

One of the most important aspects of land development from the fire protection viewpoint is access. It involves a great deal of engineering and expense and is almost impossible to improve or alter after development is complete. If inadequate, access becomes critical during a conflagration both from a firefighting standpoint and with regard to life safety[3] (Alger 1971, Los Angeles County Fire Dep. 1970, Los Angeles City-County Fire Bd. Inquiry 1971, Oreg. St. Dep. For. 1978a, County Sup. Assoc. Calif. 1966, Colo. St. For. Serv. 1977).

Adequate ingress and egress are necessary to allow safe and rapid passage of both fire equipment and private vehicles in opposite directions simultaneously. But they can be costly not only in the expense of road construction but also in the resulting reduction of saleable lots because they require space. This is particularly true in lot-splitting situations where the original parcel can be divided only into four or less new parcels, thereby reducing the opportunity to spread costs. Adequate access is a cost that must be borne, however, if past disasters are not to be repeated time and again (Alger 1971, Los Angeles County Fire Dep. 1970, Orange County Bd. Sup. 1976, Oreg. St. Dep. For. 1978b, County Sup. Assoc. Calif. 1966, San Bernardino County Bd. Sup. 1974).

Proposed Standards: Meet all of the following standards; deny any variances that do not show positively that they will not adversely affect firefighting and evacuation capabilities:

1. Provide two or more routes of access to a public road, preferably on opposite sides of the development (loop roads with single entry do not meet this standard).
2. Dedicate streets and roads to public use and maintenance. If they are allowed to remain private, provide for their maintenance in perpetuity.

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[4] Colo. St. For. Serv. 1977; County Sup. Assoc. Calif. 1966; Los Angeles County Fire Dep. 1970; Orange County Bd. Sup. 1976; Oreg. St. Dep. For. 1978a, 1978b; San Bernardino Bd. Sup. 1974.

3. Set minimum dedicated right-of-way at 60 feet to provide two 12-foot hard surface traffic lanes, two 8-foot parking lanes, and two 10-foot roadside strips wherein fire hazards shall be abated.
4. Base minimum centerline radius of curvature of streets and roads on fire hazard severity classification: moderate—50 feet, high—75 feet, extreme—100 feet. Allow no variance to less than 50-foot radius.
5. Establish road grade based on fire hazard severity classification: moderate—12 percent, high—10 percent, extreme—8 percent. Allow no variance to exceed 200 feet in length or 2 percent above standard, and only on straight line portions of the road.
6. Do not permit any dead-end streets. Allow cul-de-sacs provided they do not exceed these lengths based on fire hazard severity classification: moderate—800 feet, high—700 feet, extreme—600 feet. Require cul-de-sacs to have a turning area at the end of not less than 90-foot diameter.
7. Require bridges to have a minimum load limit of 36,000 lbs. (18 tons), and to not be narrower than the driving portion of the road serving each end.
8. Stipulate that each lot or parcel must have direct access to a road meeting the above standards, such access to be traversable by a modern structural fire engine.
9. Design road and street intersections to be as close to 90 degrees as terrain will permit, for at least 80 feet from intersection centerlines, and in no case allow the angle of such road intersections be less than 45 degrees.
10. Clear the area within 200 feet on each side of the centerline of all roads and maintain it to fuelbreak standards—except for structures.

Water Supply

Water is still the most effective tool for fighting wildland fire when and where it can be obtained in sufficient quantity. It is really the only effective tool for fighting home and most other structural fires. Therefore, a large, dependable source of water above that required for normal daily domestic purposes must be provided for at the time a subdivision (including mobile home park), shopping center, recreation area, or individual homesite is planned and developed[3] (Alger 1971, County Sup. Assoc. Calif. 1966, Natl. Fire Prot. Assoc. 1974).

The amount of water reserved for firefighting purposes and the size and type of delivery system provided depend on (a) the degree of wildfire hazard involved (fire hazard severity classification); and (b) the type and location of the occupancy (home or mobile home in a subdivision; farm or other individually developed homesite; multiple such as commercial, recreational, industrial, apartments, etc.). The water requirements for multiple occupancies are usually stipulated by the insurance carrier or local fire department or both. Although normally based on requirements for fighting an interior fire, they are usually adequate for protecting the building from an encroaching wildland fire as well, because usually these requirements are set quite high to reflect both the financial property risk and the multiple life risk.

Adequate water for firefighting purposes, either by a fire department or by the occupant, has been unavailable and unreliable on many occasions where homes were involved. In some cases, adequate water was available but not developed, as the potential fire problem was not recognized. In other situations the problem was recognized but considered a remote possibility. Sometimes the cost was considered too high. Sometimes a sufficient water supply was not available at any price—and in such a situation, the structure should not have been built. A common cause of water deficiency is the practice of extending or adding on to a subdivision where the water system was adequate for the original development and is adequate for domestic service to the addition but is insufficient to provide fire flows both to the original and to the additional developments.[3] (Alger 1971, Los Angeles County Fire Dep. 1970, Orange County Bd. Sup. 1976, County Sup. Assoc. Calif. 1966).

In contrast to normal daily use, consumption of water for firefighting purposes is of relatively short duration but of high volume. Water is also used during emergency conditions when electric power service may well be interrupted. Different engineering, therefore, is required than would be needed for a purely domestic water system. Water supplies for firefighting involve large storage facilities, high-volume mains, and dependable delivery (either gravity or pumps with alternate standby power sources). These facilities should be provided during the development phase as their price skyrockets if they must be added after development and occupancy[3] (Orange County Bd. Sup. 1976, Oreg. St. Dep. For. 1978b, County Sup. Assoc. Calif. 1966, Natl. Fire Prot. Assoc. 1974).

Proposed Standards: Adhere to the following standards as they apply to individual projects, and do not permit variances because they would expose both life and property to unacceptable risks:

1. All structural developments regardless of type or location to have a dependable supply of water adequate for both normal daily consumption and emergency fire needs.
2. Where homes or other small buildings are supplied by their own independent water systems, they are to have a minimum storage capacity of 2500 gallons, supply mains of at least 1½-inch diameter, one 1½-inch standpipe conveniently located for fire engine filling, and at least two hose outlets 50 or more feet

from the building in addition to outlets on the exterior of the building.

3. The water systems of commercial, industrial, recreational, and multiple-dwelling (apartment or condominium) developments are to be engineered to meet Standard 1 above and approved by the fire agency having jurisdiction.
4. Subdivisions and mobile home parks are to be provided with 6-inch or larger circulating (loop) mains and storage capacity sufficient to provide the minimum fire flow indicated below for at least 2 hours with a residual pressure of 30 lb/in^2, and have fire hydrants of at least 6-inch diameter with these maximum spacings:

Hazard class:	Hydrant spacing *(ft)*	Minimum flow *(gal/min)*
Moderate	700	500
High	500	750
Extreme	300	1000

5. Any area large enough for helicopter landing and take-off (e.g., school yard, parking lot) is to have at least one hydrant.

Perimeter Protection and Fire Access

The point or line at which the urban/wildland interface is most critical is the edge of the undisturbed native vegetation nearest to the structure. For a farm or other wildland home, this is the edge of the clearing made for that building. How thorough and extensive the clearing must be is the subject of various State and county laws. The same laws apply to clearing around buildings in subdivisions and mobile home parks, but are seldom adequate to meet the life and property threats involved in these more densely developed areas. What is needed in these developments is some sort of perimeter clearance or treatment of the native vegetation to a greater distance from the structures than that required by existing statutes and ordinances (Orange County Bd. Sup. 1976, Oreg. St. Dept. For. 1978b, County Sup. Assoc. Calif. 1966, Task Force on California's Wildland Fire Probl. 1972).

The greatest distance to which vegetative treatment is required by any existing law is 100 feet from the structure. Perimeter treatment around subdivisions and other high value areas (e.g., mobile home parks, recreation areas, shopping centers) should be at least to fuelbreak standards (200 feet minimum). And it should embody certain additional features for two reasons: (a) Vegetative and structural fuels must be physically separated by enough distance to reduce to an acceptable level the danger of ignition of structures by direct flame impingement or radiation—an even greater clearance (usually impractical if not impossible) would be necessary to protect against windborne firebrands; (b) firefighters must have a place in which to fight the fire before it reaches the structures, and so it is necessary to incorporate features which allow access by the firefighters and their equipment to the treated area (Los Angeles County Fire Dep. 1970, Orange County Bd. Sup. 1976, County Sup. Assoc. Calif. 1966, Green 1977).

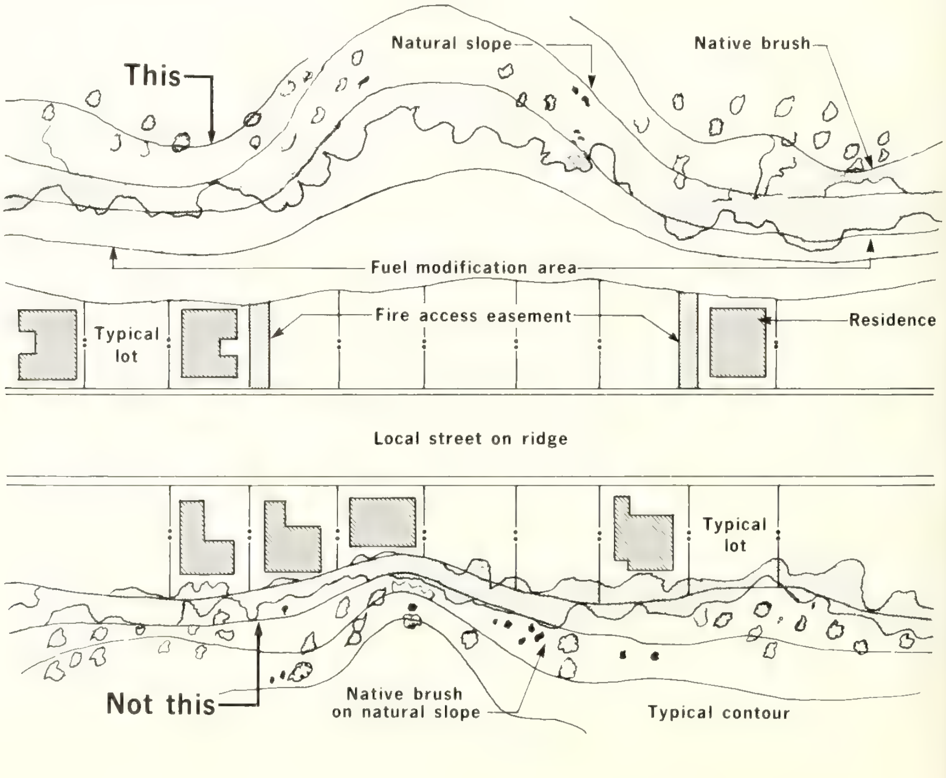

Figure 5—Fire access easements are needed for firefighters to get to areas treated for fuel modification (Orange County Bd. Sup. 1976).

This dual need can be met in several ways and many combinations thereof. Probably the best means from the firefighter's standpoint is a perimeter street with structures on the inside and a fuelbreak or greenbelt on the outside. Usually this design is economically feasible only if the adjacent area is to be subsequently subdivided. In certain topographic situations, such a design is impossible (Orange County Bd. Sup. 1976).

Another way to achieve perimeter protection is to construct a fuelbreak or greenbelt behind the outside structures (*fig. 5*). Fuelbreaks are strips of land in which the volume of vegetative fuel is reduced to an acceptable level and maintained in that condition. Greenbelts are similar strips of land wherein not only is the volume of native vegetation greatly reduced but much or all of it is replaced with irrigated introduced species. Strip parks and golf courses, are examples of greenbelts. They perform multiple functions (i.e., fire protection, recreation, esthetic benefits) and can often be made to pay for themselves (Los Angeles County 1973,, Green 1977).

Although practical in economic and sometimes physical terms, fuelbreaks or greenbelts present some problems. Access to the treated area by firefighters is denied unless fire access easements are provided and dedicated to such use. These easements should be wide enough and of low enough gradient to allow access by motorized fire equipment as well as by personnel (Orange County Bd. Sup. 1976, County Sup. Assoc. Calif. 1966).

Other developments which can serve the purpose of perimeter fire protection, at least for limited pieces of the perimeter, are recreation areas (particularly water-based ones), parking lots, school yards, and baseball or other athletic fields. With such developments placed on the perimeter the amount of otherwise unproductive fuelbreak and easements needed would be reduced[3] (Alger 1971).

Proposed Standards: Include reduction of native vegetative fuels to at least fuelbreak standards as part of perimeter fire protection for subdivisions and mobile home parks. Provide access lanes to the treated area at least 12 feet wide for firefighting manpower and ground equipment at intervals not to exceed one-quarter mile. Base the minimum width of the treated strip on fire hazard severity classification: moderate—200 feet, high—300 feet, extreme—400 feet. Dedicate such treated areas and access lanes to public use and provide for their maintenance in perpetuity.

Electric Power Distribution

Overhead transmission and distribution of electric power is a major source of ignition for the conflagrations that have destroyed many hundreds of homes in California and elsewhere in recent years. Contrary to popular belief the large high-voltage transmission lines are not the worst offenders. In one study they accounted for less than 8 percent of the fires over 5000 acres in size. They are commonly built of sturdy materials, maintained with adequate vegetative clearances, and inspected frequently and thoroughly (Task Force on California's Wildland Fire Probl. 1972, Moore 1977).

Distribution circuits accounted for nearly 17 percent of the conflagrations studied (Task Force on California's Wildland Fire Probl. 1972). This proportion was exceeded only by arson and was equalled by machine use. All other fire causes were smaller in number. Distribution circuits are of two types: primary and secondary. Primary circuits bring the power from the substation to the user's transformer. Primary electric power distribution circuits are a serious cause of wildland conflagrations. The thousands of miles of these lines present a tremendous exposure and an almost insurmountable problem of inspection and maintenance. Secondary circuits, which convey power from the transformer to the point of use (e.g., home, pump), usually cause fires because of inadequate vegetative clearance which is not now regulated by any State or local law. Secondary circuits cause nearly one fire for every two caused by primary distribution lines (Calif. Div. For. 1972, Moore 1977).

In about the lower half of their voltage range (i.e., 2.4 to 17 kilovolts), primary distribution circuits can successfully be installed underground rather than overhead. In the foreseeable future, even higher voltage lines can be installed underground. The subdivision codes of many cities now require such installation in all new subdivisions, although usually for visual esthetic reasons. The same requirement could be imposed in rural and wildland areas for fire protection reasons. Such a requirement would eliminate both primary and secondary circuits as sources of vegetation fires since the transformers would be at ground level or below. From this location the secondary circuit (service drop) is almost always placed underground also (Governor's Study Comm. Conflagrations 1966, Task Force on California's Wildland Fire Probl. 1972, Moore 1977).

If for some reason (e.g., excessive rock, preexisting overhead service) the cost of underground installation cannot be justified in relation to fire safety benefits, the developer should arrange for and the permitting agencies require very high standards of construction, vegetative clearance, inspection and maintenance of overhead power lines (Governor's Study Comm. 1966, Oreg. St. Dep. For. 1978a, County Sup. Assoc. Calif. 1966, Task Force on California's Wildland Fire Probl. 1972, Moore 1977).

Proposed Standards:

1. Install all new distribution circuits and extensions of existing circuits underground in fire hazardous wildland areas, if technologically feasible.

2. Place underground, all distribution circuits (new or existing) carrying less than 20,000 volts in areas of "extreme" fire hazard severity class.
3. Maintain the following clearances between vegetation and conductors (wires) for all overhead power lines:

Fire hazard severity class:	Secondary distribution	Primary distribution	
	0-750 volts	2.4-17KV	18-35KV
		Feet	
Moderate	2	4	6
High	4	6	8
Extreme	6	8	10

Street Names and Numbers

Subdivisions are usually provided with visible street names or numbers and lot or building numbers as a convenience to the buyers and visitors. Often, however, the signs are hard to read, sometimes even difficult to find. Many rural and mountain areas have become essentially urbanized through lot splitting and other sale of individual parcels and subsequent construction, and in these situations there is no developer to assign names and numbers. Roads often get their names from their destinations, names of old-time property owners, etc. Parcels or homes commonly are assigned box numbers by the Postal Service.

Positive identification of location is not merely convenient to a firefighter or other public safety officer responding to a reported emergency or radioing for help; it is an absolute necessity. Developers or others assigning and posting names and numbers can greatly assist in providing adequate fire protection if they will make the signs as permanent as possible and large enough and with enough color contrast and reflective character to be read easily from a moving vehicle at night as well as in the daytime[3] (Oreg. St. Dep. For. 1978a, Oreg. St. Dep. For. 1978b, Task Force on California's Wildland Fire Probl. 1972, Colo. St. For. Serv. 1977).

Proposed Standards: Construct signs of nonflammable materials, with letters at least 3 inches high, half-inch line width, and a reflective color that contrasts sharply with the background of both the sign itself and the surrounding vegetation.

Fire Station Sites

Existing fire stations in wildland areas usually are not located correctly nor are they manned and equipped adequately to provide structural fire protection to subdivisions and other developments. Developers of large subdivisions or mobile home parks or of shopping centers or apartment or condominium complexes should recognize this deficiency and dedicate one or more sites for structural fire stations at the outset. After development is complete, suitable sites will no longer be available (Oreg. St. Dep. For. 1978b, County Sup. Assoc. Calif. 1966, San Bernardino County Bd. Sup. 1974, Colo. St. For. Serv. 1977).

Proposed Standards: Dedicate fire station sites when:
1. No fire station capable of providing structural fire protection exists within 4 miles of the development.
2. The development is to encompass more than 640 acres or is to have an occupant density of more than eight dwelling units per acre.

STRUCTURAL DESIGN AND CONSTRUCTION

Because of the behavior of wildland fires, how a building is designed and constructed is the most important factor in providing fire safety for a home or other structure. Properly built homes can survive conflagrations even if many of the other protective measures discussed in this report are absent. Even homes apparently well separated from wildland vegetation will be destroyed if poorly designed and if constructed without regard to fire safety. The architect and building contractor, therefore, are key figures in providing safety. Many others (e.g., legislative and governing bodies, building inspectors, financers, insurers, buyers) need to be knowledgeable and be able to exert pressure that will guarantee adherence to fire safe practices in design and construction.[3,5]

Roofing

The roof is the most vulnerable part of a building during a fire—especially one in chaparral or oak areas. Because of its horizontal component, a roof can catch and hold the flying firebrands almost invariably associated with the strong winds and convection columns characterizing these fires. Unlike ground fire, these firebrands soar beyond any type of firebreak, natural or artificial, and thus endanger structures as far as a mile away from the wildfire (Alger 1971, Los Angeles County Fire Dep. 1970, Howard and others 1973, Lowden and Degenkolb 1972, Smaus 1978b, Wilson 1962).

Recognizing this vulnerability to fire from external sources, the Uniform Building Code requires "fire-retardant roof coverings" in Fire Zones I and II, the high value and high life hazard areas in or near the business sections of cities. Many local jurisdictions have adopted the UBC by reference or by basing their own code on it. A few local jurisdictions have amended the UBC or their own codes to require "Class C" or better roofing as defined in UBC Standard 32-7 in wildfire hazardous areas. Most wildland areas still have no requirements regarding roofing materials (Build. News, Inc. 1977, San Bernardino County Bd. Sup. 1977, Los Angeles County 1937, Intl. Conf. Build. Off. 1976, Holmes 1971).

Most structures at or near the urban/wildland interface are either not covered by a building code, are in Fire Zone III, or are permitted to have any type of roofing material, or at most, Class C roofing. In the past 30 or 40 years, wood shingles or shakes have become popular with architects and buyers alike. Various fire-retardant treatments have been available for about 20 years, but only in the past 10 years or so have any of them been made relatively permanent (i.e., will retain a significant degree of fire-retardancy for 5 years or more). Although shakes and shingles with Class C rating are available, none meet the Class B requirement for "fire-retardant" roofs as defined in UBC Standard 32-7.

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[5] Alger 1971; Task Force on California's Wildland Fire Probl. 1972; County Sup. Assoc. Calif. 1966; Howard and others 1973; Lowden and Degenkolb 1972; Oreg. St. Dep. For. 1978a; Smaus 1978a, 1978b; Wilson 1962.

Treated shakes or shingles cost more than untreated, and in the absence of a local code requiring them are seldom installed. Thousands of homes and other buildings exposed to the threat of wildland fires, therefore, are roofed either with untreated shakes or shingles, with ones which were merely dipped in fire-retardant chemical, or with ones from which the treatment has been leached by the weather. These roofs are not only serious hazards to the buildings on which they are installed but also to any other buildings downwind from them which are similarly roofed. Once a shake or shingle roof catches on fire, shakes or shingles peel off and are carried as new firebrands on the convection column and the wind.[6]

Many types of firesafe roofing materials are available. Some are less expensive than wood shakes or shingles, others more costly. They include Class A and B built-up assemblies, Class A and B prepared roofing, properly installed Class C mineral surfaced asphalt shingles, asbestos cement shingles or sheets, concrete slabs, metal, slate shingles, fiber glass shingles, and clay or concrete tile. Although most of these materials are not currently popular for residences, many can be made quite attractive—especially if the rest of the building is designed to accommodate them (Oreg. St. Dep. For. 1978a, Intl. Conf. Build. Off. 1976, Smaus 1978a).

The probability that a house of a given roof type and with brush clearance will be burned can be estimated from records compiled by the Los Angeles City Fire Department for the 1961 Bel Air Fire, in southern California. These records cover a sampling of 1,850 homes. For the probabilities shown it is assumed that houses are exposed to the rate of wildfire destruction observed in the Bel Air Fire. Values have been interpolated to match the brush clearance categories of the insurance industry (Howard and others 1973):

	Roof type	
Brush clearance (ft):	Approved by insurance industry	Unapproved by insurance industry
0 to 30	0.243	0.495
30 to 60	.054	.286
60 to 100	.016	.144
100+	.007	.148

The most cost-effective means of protecting homes from destruction by fire in or near the wildlands is a combination of approved fire-resistive roofing and clearance of 100 feet or more from the native brush for each home (*fig. 6*).

Proposed Standards: Base roofing materials required on the following fire hazard severity classification: moderate—Class C, high—Class B, extreme—Class A.

Vents

Another Achilles' heel to the attack of homes by windborne firebrands is an unprotected attic or underfloor vent. Although unprotected vents are not as well-documented as a cause of structure fires as flammable roofs, flying embers can easily enter a structure through such vents. If they land on any ignitable material, the inaccessability of the interior to suppression efforts almost certainly will lead to destruction of the house. The presence of flammable materials (e.g., dry leaves or grass, waste paper) is almost assured by the same mechanism—strong wind—that brings the firebrand. To remove this hazard, vents can be screened to prevent the entrance of flammable materials and firebrands but still allow the passage of air.[3, 7]

Proposed Standards: Use vent screens of corrosion-resistant wire mesh with a mesh size of one-quarter inch.

Overhangs and Stilt Construction

Two other common architectural practices present serious fire hazards to a home built in or near the wild-

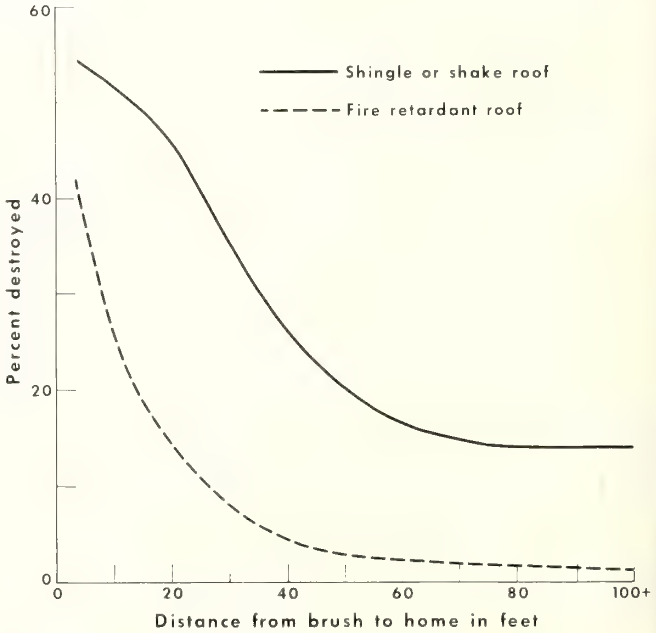

Figure 6—The greater the distance between a dwelling and brush, the better the chance it has of escaping destruction in a fire (Wilson 1962).

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[6] Alger 1971, Holmes 1971, Howard and others 1973, Los Angeles City-County Fire Bd. Inquiry 1971, Los Angeles County Fire Dep. 1970, Lowden and Degenkolb 1972, Wilson 1962.

[7] Building News, Inc. 1977; Task Force on California's Wildland Fire Probl. 1972; Governor's Study Comm. Conflagration 1966; Howard and others 1973; Los Angeles Fire Dep. 1970; Natl. Fire Prot. Assoc. 1974; San Bernardino County Bd. Sup. 1977; Wilson 1962.

lands: (a) overhanging or projecting members (e.g., eaves, balconies, raised sun decks), which are likely to be found anywhere and are always dangerous; and (b) stilt construction. The latter, although dangerous anywhere, is particularly so on sidehill sites because the uphill side forms a trap for heat and flames. The danger, directly caused by vegetative fuels being under the building, is then aggravated by the wind accompanying conflagrations (County Sup. Assoc. Calif. 1966, Colo. St. For. Serv. 1977, Wilson, 1962).

Structures with overhangs or stilt construction, or both, are usually ignited by flames sweeping against the underside of the projection or the building itself. A wildfire running uphill ahead of a strong wind through heavy brush or timber to within a few feet of a house built on stilts and with a cantilever balcony and 4- or 5-foot eaves is a positive prescription for disaster. This sequence is not as uncommon as it might sound. Hillside homes often offer spectacular views, and balconies are often provided to take full advantage of the view. Wide eaves are commonly built to shade windows. On a hillside, one side of a house may be at ground level or below while the other side is 15 or 20 feet, or possibly more, above ground level (Deeming and others 1977, Helm and others 1973, Smaus 1978b, Wilson 1962).

These architectural fire hazards can be overcome by a number of measures. One is to construct any overhanging member or building of nonflammable materials (e.g., metal or concrete) of at least 1-hour or 2-hour fire resistive materials as defined in the UBC. Another is to encase stilts so that there is no opening below the floor of the building, balcony or sun deck. Roofs can be built without eaves. Sidehill houses can be designed with two or three floor levels, thus utilizing what otherwise would be not only a fire trap but wasted space.[3,4]

Proposed Standards:

1. Construct eaves, cantilever balconies, and other similar overhangs with undersides of materials that meet the following UBC specifications, depending on fire hazard severity class: moderate—fire-retardant pressure treated wood or equivalent; high—1 hour; extreme—2 hour.
2. For structures supported wholely or in part on stilts, encase all underfloor areas to the groundline with materials meeting the standards for exterior vertical walls in the same area or zone.

Glass

Windows can easily be a weak point in the fire protection of a home for two reasons. They allow entrance of radiated heat of such intensity that interior materials (e.g., furniture, drapery, clothing, papers) are ignited. And they admit convective heat, firebrands, or flames when they are open or broken. Large picture windows and sliding glass doors are particularly vulnerable to these hazards. The orientation of the glass surface will determine the degree of hazard it represents. If it is on the windward side of the building or is facing toward a concentration of vegetative fuel, the danger is heightened. If it is downwind or shielded by some nonflammable obstruction, the danger will be reduced (Alger 1971; Los Angeles County Fire Dep. 1970; Lowden and Degenkolb 1972; Smaus 1978a, 1978b; Wilson 1962).

Windows cannot be abandoned or prohibited. The opportunity to enjoy a spectacular view or the feeling of spaciousness afforded by a sliding glass door opening onto a patio, sun deck, or swimming pool is hard to give up. But the danger of fire can be reduced by installing nonflammable shutters or fire-retardant drapes; by orientating away from concentrations of vegetative fuels; by shielding with nonflammable balconies or decks; and by using tempered or double-paned windows or both, or wire glass (Orange County Bd. Sup. 1976; Oreg. St. Dep. For. 1978a; Task Force on California's Fire Probl. 1972; Lowden and Degenkolb 1972; Smaus 1978a, 1978b).

Proposed Standards:

1. Hold to a minimum the size and number of glazed openings on the side of the house facing the normal fire carrying wind or the downhill side or both.
2. Use extra-strength glass (thick, safety, tempered, or double-paned, or both).
3. Protect windows and sliding glass doors with nonflammable shutters, balconies or decks, and fire-resistant drapes.
4. Orient any glazed openings so that they do not face concentrations of vegetative fuels within 100 feet, unless such openings are provided with fireproof shutters.

Siding

Most home fires in urban areas have internal sources of ignition. Therefore, the materials of which their exterior walls are constructed are of relatively minor importance from a fire protection standpoint. The architect, therefore, has considerable latitude in design. By contrast, home fire ignitions during a wildfire are almost entirely external (assuming all openings are protected as discussed earlier). Thus fire-resistancy of exterior walls becomes of great importance, and the choice of materials must be restricted. Contrary to this safety requirement is the strong tendency on the part of both architects and buyers toward an increasingly rustic appearance as the site gets deeper into the chaparral or

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[4] Building News, Inc. 1977; Task Force on California's Wildland Fire Probl. 1972; Colo. St. Forest Serv. 1977; County Sup. Assoc. Calif. 1966; Int. Conf. Build. Off. 1976; Lowden and Degenkolb 1972; Smaus 1978a, 1978b.

woods. As a result many structural fires in rural areas have started by direct ignition of external wood siding, garage doors, and porches. This hazard is heightened if concentrations of fuels (e.g., vegetation, firewood, wood fences) are too close to the wood-encased house (Alger 1971, Los Angeles County Fire Dep. 1970).

Many materials are available for exterior wall use that have varying degrees of fire-retardance up to 2-hour ratings or even higher. Some of these can be made to appear quite rustic. Others have unique visual qualities of their own. They vary in ascending order of fire safety from wood siding or panels pressure-treated with fire-retardant chemicals (same leaching problems as for shingles and shakes) through stucco, metal siding, brick, asbestos-cement shingles or corrugated panels to concrete block or poured concrete and rock walls. To achieve full fire-resistant effect, all but the solid concrete or rock walls must be properly applied over suitable base materials, as defined in the UBC, continuously from the ground or foundation to the roof or eaves[3] (Orange County Bd. Sup. 1976, Oreg. St. Dep. For. 1978a. County Sup. Assoc. Calif. 1966, Intl. Conf. Build. Off. 1976, Smaus 1978a).

Proposed Standards:

1. Build exterior walls of such materials as to provide the following degrees of fire resistance based on fire hazard severity class; moderate—fire-retardant pressure-treated wood or equivalent; high—1-hour, extreme—2-hour.
2. Extend the applicable degree of fire-resistance of all exterior walls from ground level to roof line.

External Sprinklers

Sprinklers permanently mounted on the roof have been suggested as a defensive measure, particularly in order to offset the hazard of wood shingles or shakes, either treated or untreated. Such sprinklers could be either automatic, similar to internal fire sprinklers, or activated manually by the occupant. However, most authorities argue against the value and advisability of sprinklers as a viable alternative to safe roofing materials. Sprinklers could, theoretically, prevent roof ignition from flying firebrands, but rather large volumes of water would be required at a time when loss of water pressure can normally be expected. Also, if activated too soon, a sprinkler system will contribute to the loss of water pressure and very likely cease to function before the actual danger arrives. In this case its benefits would be almost totally lost by evaporation, and it does not appear to be an adequate substitute for approved fire-resistant roofing material[3] (Alger 1971, Los Angeles City-County Fire Bd. Inquiry 1971, Smaus 1978b, Wilson 1962).

Proposed Standards: Allow permanently installed roof sprinklers only where the structure has its own independent water source that will not deplete the supply of water for nearby properties nor for use by organized firefighting manpower and equipment. Such systems, when installed, should have a dependable water source (gravity or alternate power).

Safety of Human Life

Of even greater importance than protecting homes from destruction by wildland fire is avoiding the loss of human life. No structure should be designed and built in any way that could trap people inside while it is burning. Occupants should have ample warning and positive means of exit (Governor's Study Comm. 1966).

Proposed Standards:

1. Install in each dwelling unit one or more smoke detectors—at least one of which shall be in or near sleeping areas.
2. Install in each dwelling unit at least two door exits by means of which ground level may be reached.
3. Install in each room, especially each bedroom, two means of exit—one of which must be to the outside of the building.
4. If a window provides one of the exits it must be no more than four feet above floor level and capable of providing an opening no less than 22 inches in least dimension and 5 square feet in area.

Mobile Homes

Mobile homes have grown remarkably in numbers in rural areas in the past 10 years, both in mobile home parks and as substitutes or replacements for detached single family residences. They are subject to all the fire problems and vulnerabilities discussed earlier for conventionally constructed houses and a few of their own. Insofar as possible mobile homes should conform to the same recommendations and standards as conventional homes in the interests of fire safety for both the building and its occupants (Los Angeles County Fire Dep. 1970, Oreg. St. Dep. of For. 1978a).

Mobile homes usually stand a reasonable chance of avoiding roof fires from windborne firebrands because most of them have insulated metal roofs. On the other hand, since the metal involved is usually fairly thin aluminum, heavy long-burning firebrands can melt through the roof and fall inside where they may ignite furnishings.

Of greater concern and probability is the danger of fire coming under the structure and igniting the floor. The best way to avoid this is to provide complete skirting, preferably metal, from floor-line to ground-line all the way around the home. Such skirting requires proper venting which should meet the same mesh or opening standards as for conventional homes (Oreg. St. Dep. For. 1978a).

Other fire problems common to mobile homes are unprotected sliding glass doors and picture windows, wide carports and porch canopies attached to the main structure, and carpeted or exposed wood porches or sun decks. Large panes of glass need some kind of protection from breakage which would allow an external fire to enter the structure. Any overhang will trap and intensify heat and flames. Flammable horizontal surfaces will collect windborne firebrands.

Probably the greatest fire safety problem of mobile homes (and this also applies to all types of recreational vehicles) is the life hazard. The fatality rate for this type of structure per 100,000 fires is several times that for conventional homes. There are three causes for such a high fatality rate: (a) the flash nature of interior fire spread often encountered in these units; (b) highly toxic and very thick smoke and gasses are given off by the many plastics commonly used in the interior; (c) the generally inadequate exit or escape capability of mobile homes. Mobile homes rarely have more than two exterior doors. Most of their windows or the individual panes, except for a picture window in the living room, are too small and too high off the floor to allow a person to climb out.

Proposed Standards: Require mobile homes to meet the same standards of fire safety as conventionally built houses, and, in addition, be provided with (a) full skirting; (b) a means of quickly enclosing, or detaching, carports and porch canopies during fire emergency situations; and (c) nonflammable, or at least fire-retardant, porches and sun decks, if any such areas are provided at all (carpeting of such areas should be prohibited).

LANDSCAPING

The proximity of a structure to native vegetation is a direct measure of the probability of its destruction by conflagration sooner or later. Flammable roofs and inadequate brush clearance are by far the most significant contributors to hazard and their elimination would provide the most cost-effective prescription available (*table 3* and *fig. 7*). Nonflammable roofs and brush clearance are not the only protective measures needed; however, they are the most critical and, if resources are limited, should receive top priority (Alger 1971, Los Angeles County Fire Dep. 1970, Los Angeles City-County Fire Bd. Inquiry 1971, County Sup. Assoc. Calif. 1966, Howard and others 1973, Wilson 1962).

Total removal of all vegetation for a specified distance from a house is impractical for several reasons. Not only would the resulting denudation be unsightly but it would create several other problems (e.g., dust, erosion). The obvious alternative is suitable landscaping. In its simplest and least expensive form, such landscaping would be essentially the type of treatment given areas chosen for fuelbreaks in the wildlands. In its most advanced form it might take the shape of an irrigated and shaded lawn or an intricately designed planting of carefully selected fire-resistant or low fuel-volume plants. In any event, the purpose is the same: to reduce heavy loadings of vegetative fuels sufficiently far from the structure to avoid ignition of the building by radiated heat or direct impingement of flames and to allow firefighters a place in which to work when it becomes necessary to save the house[3] (Alger 1971, Los Angeles County Fire Dep. 1970, Los Angeles County 1973, Pacific Southwest For. and Range Exp. Stn. 1963, Wilson 1962).

Table 3—*Differences in protection policies involving brush clearance and roof conversion, costs, and homes destroyed, Santa Monica Mountains, southern California*

Protection policy	Homes destroyed annually	Annual cost of protection program	Average annual cost plus loss to society, including program cost
	Avg. no.	MM dollars[1]	MM dollars[1]
Present situation: existing roof types and brush clearance	60	0	11.0
Native brush removed 100 feet from all homes with existing roof types	45	0.6	9.6
Conversion of all wood roofs from unapproved to approved type with existing brush clearance	21	3.1	8.9
Both brush clearance to 100 feet and conversion to approved roofs	7	3.7	7.6

Source: Howard and others (1973).

[1] 1973 dollars.

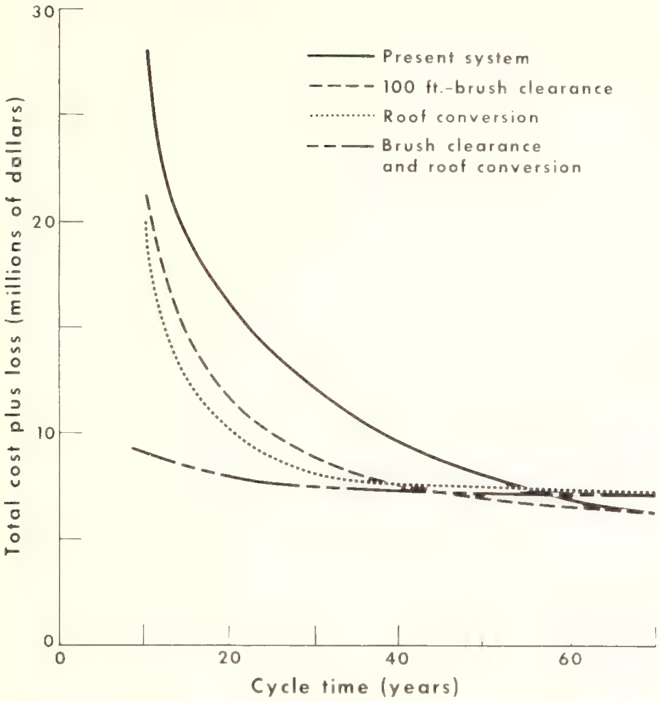

Figure 7—The cycle or average time between chaparral fires is estimated to be 30 years. Costs can be reduced by brush clearance or roof conversion or both (Howard and others 1973)

Native Vegetation

The first step in landscaping for fire protection is to remove flammable native vegetation, which includes naturalized introduced species (e.g., eucalyptus), for some distance in all directions from the structure. California State Law (Section 4291, Public Resources Code) and ordinances of several local jurisdictions require clearance for 30 feet. A few local ordinances require it for 100 feet, but these laws and ordinances generally do not mean complete denudation of the land. The key word is "flammable," usually interpreted to mean all dead vegetative matter and enough live crowns to avoid the direct spread of fire from one tree or bush to another. To complete the job properly, remaining crowns should be pruned enough to avoid their ignition by a ground fire (*fig. 8*) (Alger 1971, County Sup. Assoc. Calif. 1966, Los Angeles County 1973, Pacific Southwest For. and Range Exp. Stn. 1963, Green 1977).

Seldom is a 30-foot brush clearance adequate to protect a home from wildfire. California State law recognizes this fact by providing for an extension to 100 feet upon a finding of necessity by the Director of Forestry. Likewise several local ordinances in southern California require a minimum clearing of 100 feet. Even these distances may not be enough. Several fuelbreak planning and design studies on intensity of radiated heat and on flame lengths under high wind conditions indicate that 200 feet may be more appropriate under conflagration conditions. Actual brush clearance needs on the ground cannot be legislated. They are determined by native fuel loading, slope, expected wind velocity, and types of building materials to be protected. In certain situations, a 400-foot clearance may be barely adequate[3] (County Sup. Assoc. Calif. 1966, Los Angeles County 1973, Pacific Southwest For. and Range Exp. Stn. 1963, Natl. Fire Prot. Assoc. 1974, Task Force on California's Wildland Fire Probl. 1972).

Adequate brush clearance is purely a matter of fire physics, and has nothing to do with property ownership or boundaries. Within limits it can be made easier by positioning the building with adequate set-back from all property lines. In most subdivisions, even the so-called ranch subdivisions, however, lot sizes are too small to allow for up to 400-foot clearance without some of it being on a neighbor's property. Some local ordinances take care of this problem up to 100 feet from the building by declaring any and all flammable native vegetation within that distance to be a public nuisance and requiring its abatement regardless of ownership. This approach could be extended both in distance and to other jurisdictions[3] (Los Angeles City-County Fire Bd. Inquiry 1971, Task Force on California's Wildland Fire Probl. 1972, Howard and others 1973).

Any of several methods of vegetation removal may be used, depending on cost, timing, final result desired, topography, and rock outcroppings and would include hand chopping, bulldozing, discing, and burning. Killing with herbicides does not, in itself, accomplish the purpose. In fact, if the dead plants are not removed, the fire hazard is increased rather than reduced. Removal by one of the other methods while the plants are still live is usually easier (Pacific Southwest For. and Range Exp. Stn. 1963, Green 1977).

Proposed Standards: Require native vegetation clearance and thinning, regardless of property ownership, for the following distances from structures:

Direction from structure:	Fire hazard severity class		
	Moderate	High	Extreme
		feet	
Upslope—25 pct +	30	60	100
Across slope or 0–25 pct	60	100	200
Downslope—25 pct +	100	200	400

Plantings

In replacing the removed vegetation, keep and augment the benefits of the removal. Planted, as well as retained, native trees and bushes should be spaced far enough apart that their crowns will still be separated when full-grown. They should not overhang the house. The space between these trees and bushes should be

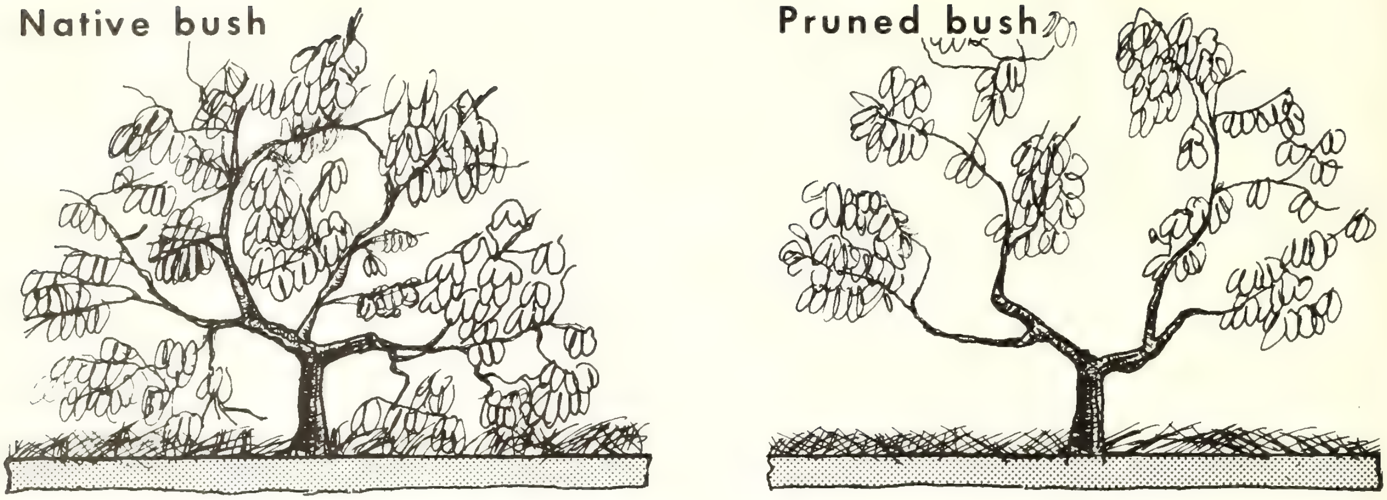

Figure 8 — Native plant species should be pruned to reduce fire hazard.

covered with relatively low-growing and fire-retardant plants, a greater variety of which exist than is commonly known. On the other hand some common landscape plants are highly flammable and should not be used. One of the best and easiest to maintain is lawn. Others include both introduced and native ground covers and small flowering plants.[9]

Much research has been done recently on so-called fire-resistant plants for home, fuelbreak, and roadside plantings. The research has included both native plants and introduced ones, the latter coming primarily from areas of the world with Mediterranean climates (e.g., Australia, Chile, South Africa, Caucasus Mountains). Although some plants burn more slowly than others because of high salt, ash, or moisture content, the difference is generally not worth the time and expense of propagating them. In recent years the focus has, therefore, been on finding plants with low volume and height, and therefore, with low heat output, as well as some degree of fire retardance (Los Angeles County 1973, Green 1977, Nord and Countryman 1972, Wilson 1974).

Several plants have desirable attributes of fire retardance, low maintenance requirements, availability and range of successful plantings. These include white trailing iceplant (*Delosperma alba*), dwarf aloe (*Aloe aristata*), shortleaf aloe (*Aloe brevifolia*), croceum iceplant (*Malephora crocea*), crocea (*Malephora crocea* var. *purpureo*), creeping Australian saltbush (*Atriplex semibaccata*), lippia (*Lippia canescens* var. *repens*), and quaking aspen (*Populus tremuloides*). At least as many others are equally effective but only in limited climatic zones. Two others show a good deal of promise in test plantings but are not yet available on the commercial market: creeping sage (*Salvia sonomensis*), and Castlevalley saltbush (*Atriplex cuneata*). A decorative plant to be avoided is any species of juniper, even the prostrate variety, as all species contain a high volatile oil content and are unusually flammable (Alger 1971, Los Angeles County 1973, Green 1977, Nord and Countryman 1972).

The initial choice and planting of the landscaping plants does not complete the job. All require a certain amount of maintenance, both to retain their fire protection effectiveness and to keep them healthy and attractive. Various plants have differing water requirements. All need weeding, at least until they get well established. Most, including the iceplants, need to have dead branches and leaves removed periodically. Lawns need to be mowed (Alger 1971, Los Angeles Times 1978, Los Angeles County 1973, Pacific Southwest For. and Range Exp. Stn. 1963, Green 1977).

Proposed Standards: Use only those plants that have been tested and proved to have significant fire protection qualities.

Irrigation and Sprinkling

Almost any landscape planting for fire protection purposes will require some irrigation—at least while it is getting established. The installation of pipes, hose bibs, and sprinklers should be part of the job. Different types of plants have different water needs, however, and thus general area-wide sprinkling should be avoided. Many of the best plants are similar to chaparral in their low water requirements and can be damaged or even killed by too much water. Other plants have fairly high water requirements. The different types should be separated and each provided with its own water source (Alger 1971, Orange County Bd. Sup. 1976, Los Angeles County 1973).

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[9] Alger 1971, Green 1977, Los Angeles County 1973, Los Angeles Times 1978, Nord and Countryman 1972, Orange County Bd. Sup. 1976, Pacific Southwest Forest and Range Exp. Stn. 1963, Wilson 1974.

It has been suggested that rather than removing the native vegetation, it be made fireproof by sprinkling or other form of irrigation. The limited research so far conducted indicates that this approach will not solve the home fire protection problem. Large quantities of water are required to raise significantly the moisture content of the soil and the live fuels in the summer and fall. And watering would stimulate growth rates, thereby increasing the quantity of vegetative fuels that then increase the heat energy released in a fire (Orange County Bd. Sup. 1976, Los Angeles County 1973, Younger 1974).

Proposed Standards: Design and install irrigation systems so that plants with differing water requirements can be irrigated separately on different schedules.

Herbicides

Many chapparral species and some other native plants are sprouters. Unless the root crowns are removed in the initial clearing process, which may not be desirable for soil erosion reasons, they will resprout quickly and profusely. If not controlled they will recapture the site within 2 to 5 years, negating both the clearing and the landscaping. The control of weeds and wild grasses among plantings must also be considered. Properly prescribed and applied herbicides are often the most effective and economical means of achieving both of these objectives (Los Angeles County 1973, Pacific Southwest For. and Range Exp. Stn. 1963, Green 1977, Harvey 1974).

Although herbicides are not useful for the initial clearance of native vegetation, they can help prevent regrowth and maintain desirable landscaping. They must, however; be used with considerable caution in order not to produce undesirable results, i.e., killing plants which have been planted at much expense in time, labor, and money. The advice, if not the services, of farm advisors, agricultural commissioners, and licensed herbicide applicators should be obtained. In some cases, alternate means of control may be better, and might include grazing and browsing by livestock (horses, sheep, goats), hand chopping or grubbing, and prescribed burning (Orange County Bd. Sup. 1976, Pacific Southwest For. and Range Exp. Stn. 1963, Task Force on California's Wildland Fire Probl. 1972, Green 1977).

Proposed Standards: Use herbicides only as prescribed by persons knowledgeable and qualified in their use and appliation.

Fire-Retardant Chemicals

The feasibility of applying fire-retardant chemicals for conflagration protection purposes to vegetation surrounding a home has not yet been explored thoroughly. These chemicals, used extensively in wildfire control, are known to have a fire suppressent effect. They do, however, have some qualities which make their use for home fire protection questionable. They are quite expensive. Although they retain their fire retardant qualities after drying, they wash off readily with light amounts of rain or sprinkling. The old ones are soil sterilants. The new ones are fertilizers which would probably promote undesirable as well as desirable growth. Arguments in their favor are that they would reduce considerably the heat energy emitted by the burning of either native or planted vegetation. Used without the dye included for aerial firefighting, they are almost colorless when dry and their application would not alter the appearance of any vegetation significantly.

MAINTENANCE

Although many of the most important actions in providing fire safety for a structure located in a wildfire hazardous area take place during the planning, designing, constructing, and landscaping phases they do not end there. Maintenance must begin the day the occupant moves in and continue so long as the building stands, or all the original built-in protection may be in vain. Many cases have been documented wherein a structure, once reasonably fire-safe, burned down after it or the area around it had been allowed to deteriorate (e.g., birds' nests under the eaves, accumulations of leaves and dry grass in yard and gardens or on roofs, regrown brush). Roofs also deteriorate in varying lengths of time and require repair or replacement (Alger 1971, Los Angeles County Fire Dep. 1970, Los Angeles County 1973, Wilson 1962).

Roofs and Rain Gutters

The roof is the most critical point in maintenance as well as in construction for the protection of a structure from a conflagration in chaparral or other wildland. The most common problem arises from the accumulation of dead leaves or needles which can build up to considerable depth in the troughs of peaked roofs, in rain gutters and behind the wall extension above the roof line that is commonly used with flat roofs. Any place where windblown leaves will accumulate is an ideal place for windborne firebrands to drop. Under these conditions even so-called ''fire-retardant'' roofs will ignite. Another attractive place for firebrands to ignite is in birds' nests under eaves and the ends of unplugged tiles. The obvious preventive solution is to remove all such accumulations before each fire season and at least once during the season (Alger 1971, Los Angeles County Fire Dep. 1970, County Sup. Assoc. of Calif. 1966).

An older home is no more immune to destruction by wildfire than is a new one. Its roof is certain to require repair or replacement eventually. When this time comes it is only good business as well as insurance for future fire safety to upgrade the fire protection rating of the materials used. The UBC and many local ordinances state that whenever 25 percent or more of a roof is replaced it must meet the standards for the fire zone in which it is located, and this is a good rule of thumb for use in wildfire hazardous areas (Building News, Inc. 1977; Intl. Conf. of Build. Off. 1976).

Proposed Standards:

1. Remove all loose flammables (e.g., dry leaves or needles, paper, birds' nests) from roofs, eaves, and rain gutters at the beginning of each fire season and any time they accumulate to a depth of 1 inch or more.
2. Not more than 25 percent of the area of a roof should be replaced within any 3-year period with materials that are not approved for new roofs in the same wildfire hazard severity classification area.

Yards

Yards, gardens, landscaped areas, and fire protection clearings require a great deal of maintenance. No vegetation is immortal, and flammable dead vegetative material is going to accumulate. Often such accumulation is not readily apparent to the unpracticed eye. Individual dead twigs and branches may be hidden by live exterior foliage. Dead leaves may be under or behind live plants. Annual grasses and weeds can grow almost anywhere. All such dead vegetative material should be removed and disposed of before it becomes tinder for carrying a wildfire to the house (Los Angeles County Fire Dep. 1970, Orange County Bd. Sup. 1976, Los Angeles County 1973, Smaus 1978b).

Even if vegetation is kept pruned and weeded, yards will collect a certain amount of flammable litter. Leaves and needles fall. Scrap paper blows in on the wind. All such material should be regularly collected and disposed of. In many areas they must be hauled away to an approved landfill either by a refuse disposal service or by the occupant because local air pollution regulations prohibit burning. In those areas where burning is permitted it should be done only in an approved incinerator under permit from the local fire protection agency. Open debris burning has caused a good many conflagrations in the past, although it has been somewhat rare in the past 10 or 12 years due to recent restrictions and controls (Alger 1971).

Because of natural plant succession, clearances around structures for fire protection will almost invariably revert to native vegetation unless positive steps are taken to maintain the clearance. Maintenance can be accomplished in several ways: by skillful use of herbicides, by browsing and grazing livestock, by disking, by hand chopping or grubbing, or by prescribed burning (*table 4*). Many people living in wildfire hazardous areas keep horses and some keep cattle or sheep. Research by the United States Forest Service and California Department of Forestry has shown that goats enjoy a diet of chaparral and are very effective at maintaining fuelbreaks. Horses, cattle, and sheep are primarily grazers and will only browse on very young succulent chaparral but are good at reducing the fuel loading of dry grass. The method or combination of methods used is not important as long as thought and effort are put into maintaining the fire protective qualities of the clearing (Orange County Bd. Sup. 1976, Los Angeles County 1973, Green 1977).

Proposed Standards: Remove and dispose of all dead vegetative and other flammable material, in amounts which will carry ground fire or convey fire from one bush or tree to another, by means permitted by State law and local ordinance.

Storage

It is common in suburban, and in rural areas especially, to store certain flammable materials outdoors, often stacking them against the side of the house, garage, or barn. The most common such materials are firewood, lumber, and hay, but there are many others. This practice is very dangerous as far as the fire safety of the structures is concerned. Stored flammable mate-

Table 4—*Relative cost of alternative methods of brush regrowth control*

Control method	Cost per acre, by year										Present value	
	0	1	2	3	4	5	6	7	8	9 and beyond	6 pct	10 pct.
	1976 dollars											
Herbicides	30	30	30				30			30 in 10th yr & every 4th yr thereafter	185	135
Goat grazing	5	5	5	5	5	5	5	5	5	5 per yr every yr	85	50
Mechanical clearing (disk)	30		30		30			30		30 in 9th yr & every 3d yr thereafter	210	145
Hand cleaning	100		100		100		100		100	100 in 10th yr & every 2d yr thereafter	875	565
Prescribed burning	20			20			20			20 in 9th yr & every 3d yr thereafter	125	80

Source: Orange County Bd. Sup. (1976).

rials should be under cover to prevent windborne firebrands from landing on them. If covering them is not feasible or it is not possible to store them inside the building then they should be separated from the building by enough distance to save the building from ignition should the materials catch fire. It is still the best practice to cover them with sheet metal or some other fire-retardant material (Alger 1971, Los Angeles County Fire Dep. 1970, Wilson 1962).

Proposed Standards: Store flammable materials either:

1. Inside of properly designed and constructed fire-safe buildings, or
2. Separated from any buildings by the same minimum distance required for building spacing in the wildfire hazard severity class in which the structures are situated.

ACCESSORIES

Although the most important factors in determining the probability of a structure surviving a large wildland fire are the materials of which a residence is constructed and its location with respect to vegetative fuels, others must also be considered. One of the more important is the number, type, and location of various accessories and their manner of installation. Some of these accessories (e.g., wood fences and outbuildings, fuel tanks) can increase the hazard. Others (e.g., brick fences, portable pumps for swimming pools) can reduce it. The effects of some (e.g., water pumps, patios) depend entirely on their manner of installation.

Swimming Pools

Wherever the water supply is adequate to support them, swimming pools have become prominent accessories to rural and suburban homes in recent years, particularly in southern California where the length of the season of their use makes the investment most worthwhile. These pools can be important for providing fire protection to the home, or they can be of no help whatsoever, depending on how they are installed and equipped. To a lesser degree the same can be said for other bodies of water on the premises (e.g., stock ponds, fish ponds, creeks) (Alger 1971, Governor's Study Comm. 1966, Los Angeles City-County Fire Bd. Inquiry 1971, Oreg. St. Dep. of For. 1978a).

The first and simplest way in which pools can be made a part of the fire protection system is their placement and screening. If located on the windward and/or downhill side of the house and screened from public view by masonry or other nonflammable wall or fence they provide a good deal of the needed separation between the structure and the native vegetation. The wall will protect sliding glass doors from radiated heat and may also provide some deflection of wind, thus assisting in protection from windborne firebrands.

The most important benefit of swimming pools or other bodies or water, however, is as a source of firefighting water, but this aid is quickly negated if there is no way to get the water. Every pool, therefore, needs to be so installed and equipped that the water in it can be obtained and used either by a fire engine or by the occupant, or preferably, by both. For the fire engine to get the water it must be able to get close enough to the pool to draft water with its pump and suction hose. If this is not a possibility the pool will need a bottom drain leading to a standpipe near the street to which the engine can hook up. For the occupant to be able to make emergency use of the water, a pumping system is needed. A gasoline-powered portable pump is best for this purpose because of the danger of electric power outages during conflagrations (Oreg. St. Dep. For. 1978a, Task Force on California's Wildland Fire Probl. 1972, Lowden and Degenkolb 1972, Smaus 1978b).

Proposed Standards:

1. Provide unobstructed direct access by a fire engine to within 16 feet of the water surface (a gate that can

be opened quickly by firemen would not be considered an obstruction).
2. If Standard 1 is physically impossible, equip the pool with a bottom drain and piping system of 2½-inch minimum diameter that terminates in a valved standpipe. Locate the standpipe where a fire engine may quickly hook up and draft water from it.
3. In addition to following either Standard 1 or 2, store a portable gasoline-powered pump, complete with 8 feet of suction hose, 100 feet of fire hose, and a fire nozzle, at a place convenient to the pool or other water source.

Fences

Fences are accessory to almost every home. They vary from barbed wire fences which are no more than barriers to certain domestic livestock through various types of decorative and visual barriers, usually made of wood, to high masonry or concrete barriers. They are equally as varied in their effects on wildland fire. Even two fences of exactly the same type may have different effects, depending on how they are maintained.

Barbed wire fences have little or no effect on a fire unless wooden posts are used or they are allowed to accumulate dry grass or other flammables. Other types of wire fences (e.g., hog wire, chain link) collect windblown paper, leaves, and other flammable trash. Unless they are cleaned regularly, they contribute to the natural fuel loading. Rail fences, whether of the post or zigzag variety, add fuels, especially after they become old and weatherbeaten. Essentially solid wood fences (e.g., board, grape stake) present the same problem as rail fences and in addition act as collectors of windborne flammables. Many documented cases point to these fences as the means of carrying the fire to the structure. Masonry or other nonflammable fences may collect flammables, but rarely to such an extent that their effectiveness as a barrier to a ground fire is seriously reduced. Although this type of fence cannot guarantee protection from windborne firebrands, it has been known to deflect them so that they land in relatively safe areas rather than on the structure or on some other accessory (e.g., wooden sun deck, patio furniture). All types of fences, including barbed wire, tend to become windrows of dry grass and weeds unless well cleaned and maintained annually (Alger 1971, Los Angeles County Fire Dep. 1970, Smaus 1978b).

Proposed Standards:
1. Construct fences to the maximum extent possible of open, single-strand wire or of solid masonry construction.
2. Keep clean of loose flammable materials any fences constructed of meshed wire or of flammable materials.

Outbuildings

Outbuildings include any and all structures associated with but not directly connected to or part of the main building (e.g., detached garages, barns, pump houses, tool houses, tree houses). They are often more vulnerable to a wildfire than is the residence. Most residences are designed and built by professionals and therefore have some degree of fire protection (although seldom adequate) built in, but outbuildings seldom are. They are usually built by the occupant sometime subsequent to, often years after, the construction of the residence. In addition, because of their lower value and the fact that humans rarely live in them, they are usually not as well cleaned and maintained as the house. They tend to start off as poor fire risks and become steadily worse. Fires have been observed spreading from burning outbuildings to residences by radiation, convection, and flying burning shingles (Los Angeles County Fire Dep. 1970).

Proposed Standards:
1. Require outbuildings to meet the same standards for building spacing, roofing materials, brush clearance, etc., as the structure with which they are associated.
2. Prohibit the use of outbuildings as depositories of discarded flammable materials.

Patios, Sun Decks, and Balconies

If made of nonflammable materials and properly designed, patios, sun decks, and balconies are not only enjoyable but also can be of considerable fire protection value. By becoming part of the brush clearance and landscaping, they help reduce radiant and convective heat on the house. Judicious orientation with respect to slope, wind, picture windows, etc., can deflect wind and heat away from weak points in the fire defenses of a home. On the other hand, if made of wood or other flammable materials, covered with carpet, congested with wood or fabric furniture, or covered by a canopy or trellis, they may easily become the direct means of transmitting fire to the house (Smaus 1978a, 1978b).

Proposed Standards:
1. Construct patios, sun decks, and balconies of concrete or other nonflammable material wherever possible; but in no case, use any materials having less than 2-hour fire-resistive rating as specified in the UBC.
2. Do not carpet any unenclosed portions of these accessories.
3. If canopies or trellises are employed, provide means for quick enclosure so that windblown flames and heat cannot be trapped beneath them.

4. If the deck or floor level of a patio or sun deck is above ground level, seal off the underside of the deck or floor by skirting or by a wall to keep fire from burning beneath it.

Water Pumps

Most rural and suburban residences in subdivisions subscribe to community water systems of some type. Many that are not in subdivisions get their water from an irrigation district or private water company. Some of the latter homes must provide pressure and storage for themselves. All other residences must provide their own complete independent water systems including well or spring, pump, and storage facilities. Wherever an occupant has to provide the pump, it must be properly designed and installed and be capable of delivering enough volume for effective firefighting, probably considerably more volume than that needed for domestic use. Most such pumps are electrically powered. Care must be taken that power to the pump is not lost at a critical time, and electric service to the pump should be separate from that to the house. Since power company distribution lines can also burn down, a standby gasoline engine-powered pump should be available. Preconnected hoses should also be available both at the pump and elsewhere about the property for immediate use in case of fire (Oreg. St. Dep. For. 1978a).

Proposed Standards:

1. Install electric water pumps with independent service drops that do not pass through or onto any building.
2. Install pumps capable of delivering a minimum of 100 gal/min at 50 lb in^2 pressure (a desirable standard would be 250 gal/min at 100 lb in^2).
3. Back up electric pumps with a gasoline-powered pump.
4. Preconnect to the pump or distribution main one or more hoses reserved for firefighting purposes and long enough to reach to all sides and the roof of each building.

Fuel Tanks

Except for suburban subdivisions and some mobile home parks, most rural and wildland residences are heated either by liquid petroleum gas or by fuel oil. In addition many farms and ranches have their own bulk gasoline tanks. If improperly installed, protected, and separated from other structures and vegetative fuels, the containers for these hydrocarbon fuels become extremely dangerous during a fire. They have been known to rupture seams, break connections, and even explode when overheated. They can burn with intense heat, often in the form of a jet aimed at a house, barn, automobile, or other valuable property. They have even been seen breaking loose from their mountings and rolling down hills scattering fire on the way. The safest practice is to have a professional install these tanks so that they are not only safe from fire themselves but will not endanger life or other valuable property in case they do become overheated (Alger 1971).

Proposed Standards:

1. Hydrocarbon fuel tanks should be installed only by persons licensed to do so and under permit. They should not be placed in operation until approved by a fire marshall.
2. Store gasoline only in properly vented underground tanks.
3. Do not mount fuel oil tanks on the side of the residence or within 15 feet of any structure.
4. Mount LPG tanks on concrete or steel cradles that will not allow the tank to roll; if they are not spherical, orient them so that neither end points toward any structure and, regardless of shape, so that the relief valve does not point at any structure.
5. Require all hydrocarbon fuel tanks to have, properly maintained, the same amount of vegetative clearing as residences and other structures in the same wildfire hazard severity class area.

OCCUPANT ACTIVITIES

Even if all the recommendations and standards set forth herein are scrupulously adhered to, it is still prudent for the homeowner or other occupant to take steps to protect self and home from fire (Alger 1971, Wilson 1962).

To be effective these steps should be taken in a logical three-part sequence: those things to be done, maintained, or practiced in advance of any emergency; those to be done when an emergency has been forecast or is likely to happen; those to be done when fire threatens the home. The steps in the last group depend largely for their effectiveness on the manner in which those in the first two groups are carried out. Similarly those in the second group depend largely on the steps in the first group having been taken.

Advance Fire Protection

The keys to an occupant's contribution to the fire defenses of the home or other structure are (a) planning of actions, and (b) providing equipment. Planning should include all those actions to be carried out, and by whom, when dangerous fire weather exists or is forecast as well as those tasks to be done when the structure is actually threatened by a wildland fire. Equipment not only needs to be acquired but must be strategically placed and its proper use for firefighting learned. All members of the family or other regular occupants of the structure must participate in the planning and training and must thoroughly understand the proper use of equipment. Planning should include alternatives so that panic or ineffective actions will not occur in case the primary plan cannot be accomplished or certain equipment fails or breaks (Alger 1971, Building News, Inc. 1977, Oreg. St. Dep. For. 1978a, Hulbert 1972, Smaus 1978b).

Proposed Standards:

1. Include in fire emergency plans the following items as a minimum:
   a. Normal and alternate escape routes in case evacuation becomes necessary.
   b. Locations of and routes to fire-safe sanctuaries (large areas with little or no fuels) where family members can ride out the fire if egress is cut off.
   c. Normal and alternate methods of communication with other family members.
   d. When to evacuate. Evacuation depends on so many variables that it can only be planned on an individual property basis and with contingent alternatives.
   e. Who is to do what when an emergency is likely and when one exists.
2. Provide the following minimum equipment for each property, preferably to be used only for firefighting or training:
   a. Hoses preconnected to all faucets; hoses should be five-eighths inch or larger inside diameter and 100 feet long.
   b. One or more long-handle, round-point shovels.

   c. One ladder long enough to reach the roof of the building easily.
   d. One rake (leaf, garden, asphalt or special firefighting).
   e. One or more 5-pound multipurpose fire extinguishers.
3. Additional desirable equipment includes.
   a. An axe.
   b. A hoe (heavy duty or special firefighting).
   c. One or more fire buckets.
   d. A backpack water pump.
   e. A portable gasoline-powered water pump.
   f. Protective clothing for anyone who may not evacuate before the arrival of a fire (i.e., boots, long trousers, long-sleeved shirt or jacket, helmet or other head covering, gloves, goggles).

Preparations for Possible Emergency

The wildland fire protection agencies in California in cooperation with the National Weather Service, U.S. Department of Commerce, have developed a Red Flag Fire Alert System. This graduated system uses watch, warning and alert stages. It usually provides fire agencies, public utilities, and other cooperators 48 hours or more advance notice of impending critical fire weather. The public, however, is usually not notified until the critical weather has actually arrived (alert stage).

Whenever a Red Flag Fire Alert is announced by the local fire protection agency or a Santa Ana or similar wind is blowing or other conditions exist that indicate that a wildland fire, if once started, would be likely to turn into a conflagration, homeowners should start carrying out their fire protection plans. At such times checklists, if not previously prepared in the advanced planning phase, should be made and put to use. The house or other structure should be placed in a maximum state of preparedness for defense against fire (Alger 1971; Building News, Inc. 1977; San Bernardino County Bd. Sup. 1974; Smaus 1978b).

Proposed Standards: Follow any checklist previously prepared and take any of the following actions that are appropriate:

1. Close all openings, including windows, doors, garage doors, vents.
2. Close window protection equipment as available (i.e., shutters, heavy drapes, venetian or other blinds).
3. Remove light flammable curtains from windows.
4. Test water system, including any pumps on the property, each valve and each hose.
5. Fill buckets and other bulk containers with water.
6. Raise the ladder to the roof near a hose bib and take the hose to the roof.
7. Bring all flammable outdoor furniture indoors.
8. Put as many motor vehicles as can be accomodated inside the garage.
9. Park all vehicles, including any in the garage, so that they are heading out toward the evacuation route.
10. Cover windows with aluminum foil or other heat reflective material.

Wildfire Approaching

When a wildfire is in progress, certain final preparations should be made and certain decisions reached even though it may not be a threat at the moment. Wildland conflagrations can and do change direction of spread abruptly as has been documented on many occasions. Preparations at this time are concerned primarily with conserving water and fuel and reducing the flammability of the building. Whether everyone should evacuate the premises or one or more persons should remain to protect the property must be decided. Children, old people, invalids and other handicapped people should evacuate, but whether all able-bodied adults should do so will depend on the circumstances. Critical factors include: availability and dependability of water, type of roof, proximity of vegetative fuels and other structures, presence of trained and equipped firefighters, adequacy of tools and equipment, and access to fire-safe sanctuaries. Cases of doubt or indecision should be resolved in favor of life safety rather than property safety (Alger 1971, San Bernardino County Bd. Sup. 1974).

Proposed Standards: Take the following actions upon the approach of a wildland conflagration:

1. Shut off any natural gas, LPG, or fuel oil supplies at a point as far from the structure as the plumbing will allow.
2. Make certain that all water is shut off except that supplying external hose bibs which may be used for firefighting. The house should be plumbed so that closing one valve will accomplish this. If it is not, close each interior faucet and valve.
3. Evacuate everyone except possibly one or more able-bodied adults properly equipped to protect the structure and themselves, provided it is safe to remain.

FINANCIAL INCENTIVES

It is neither feasible nor desirable to accomplish all the above recommendations and standards by governmental action through laws and regulations, yet they all have a price, either in money or in labor, and it is not likely that more than a small portion of the homeowners will carry them out voluntarily unless the benefits can be seen to outweigh the costs. The thousands or millions of property owners cannot be expected to be informed adequately of the hazards and risks involved in home ownership over long periods of time in areas of varying fire hazard. On the other hand the few hundred people who control insurance rates, loan terms, and taxes can, and should, be so informed and take the action to set those rates in such a way as to reflect true probabilities of loss and costs of fire suppression.

Insurance Surcharges

A so-called brush surcharge has been published by the Insurance Services Office (ISO) for a good many years. Actually it is based on a combination of factors only one of which is the amount of brush clearance. The other factors used are: type of roof, fire protection class, and response time. Although a step in the right direction, the program is only partially effective for several reasons. Most important is the fact that the surcharges do not reflect the actual probabilities of destruction by fire, and in particular show unrealistic differences between approved and unapproved roofs (20-percent difference in rate compared to 95-percent difference in loss actually measured). Because of this owners with fire-safe properties are subsidizing those with unsafe properties (*table 5*). Secondly, the surcharge schedule does not take fire hazard severity classification into account. Thirdly, not all underwriters subscribe to the services of ISO, so they are not guided

Table 5—*Alternatives in roofing, surcharges, loss, and costs for protection class 4B ($500,000 home; $10,000 potential uninsured loss)*

Alternative	Surcharge	Expected uninsured loss[1]	Program cost	Total cost
	1973 dollars			
Approved roof, 0- to 30-foot clearance	200	81	390	671
Approved roof, 30- to 60-foot clearance	180	18	423	621
Approved roof, 60- to 100-foot clearance	140	5	485	630
Approved roof, more than 100-foot clearance	80	2	530	612
Unapproved roof, 0- to 30-foot clearance	250	165	0	415
Unapproved roof, 30- to 60-foot clearance	225	95	33	353
Unapproved roof, 60- to 100-foot clearance	175	48	95	318
Unapproved roof, more than 100-foot clearance	100	49	140	289

Source: Howard and others (1973).

[1] Based on destruction rates from the 1961 Bel Air fire in southern assuming a probability of exposure in a given year of 1/30.

by its recommendations. A revised rate schedule could easily be prepared to incorporate surcharges for substandard installations and rate reductions for those with protection in excess of the standard, and based on true probabilities which would take into account the experience gained from the thousands of buildings destroyed by conflagrations in the past 10 or 15 years (*table 6*). In order to apply to all insurance companies rather than only to those affiliated with ISO, such a rate schedule could be established by the State Department of Insurance (Los Angeles City-County Fire Bd. Inquiry 1971, Howard and others 1973).

Table 6—*Alternatives in roofing, surcharges, loss, and costs under* ***revised*** *insurance surcharge rates ($50,000 home; $10,000 potential uninsured loss)*

Alternative	Surcharge	Expected uninsured loss[1]	Program cost	Total cost
	1973 dollars			
Approved roof, 0- to 30-foot clearance	736	81	390	1,207
Approved roof, 30- to 60-foot clearance	164	18	423	605
Approved roof, 60- to 100-foot clearance	49	5	485	539
Approved roof, more than 100-foot clearance	21	2	530	553
Unapproved roof, 0- to 30-foot clearance	1,500	165	0	1,655
Unapproved roof, 30- to 60-foot clearance	865	95	33	993
Unapproved roof 60- to 100-foot clearance	436	48	95	579
Unapproved roof more than 100-foot clearance	348	49	140	537

Source: Howard and others (1973).

[1] Based on destruction rates from the 1961 Bel Air fire in southern California, and assuming a probability of exposure in a given year of 1/30.

Proposed Standards:

1. In addition to the criteria already used to determine insurance surcharges, rates should reflect various levels of fire hazard severity classification.
2. Rate schedules should be revised at 5-year intervals, or oftener, to reflect actual fire loss experience from wildland fires in the previous 10- to 15-year period.

Loan Terms

Mortgage rates and other conditions of loans could be adjusted to encourage fire-safe practices in much the same manner as suggested for insurance rates. High interest rates and other unfavorable conditions for loans on substandard projects and installations coupled with lower rates and favorable conditions for those which exceed the standards would encourage the latter. Such practice is perhaps not entirely consistent with current money market practices. But since the risk is never completely eliminated by insurance coverage, such practice would represent a judicious assessment of the risks to the lender, and would be effective with home buyers. From the standpoint of public safety it would be even more effective if applied to the large loans to developers and builders. If builders sell only fire-safe homes, subdivisions and mobile home parks, the purchasers of their products will start, at least, with low-risk situations.

Proposed Standards:

1. Bare compliance with the standards set forth above should qualify for current market interest rates.
2. Progressive degrees of noncompliance with the above standards should lead to progressively higher rates.
3. Fire-safe practices in excess of the above standards, considered minimum safe practices, should qualify for rates below current market rates.

Tax Adjustments

Fire-safe practices by property owners reduce the cost of public fire protection services. The lack of such practices not only exposes the property of the owner or occupant and neighbors to increased risk of destruction by wildfire, it also makes the task of firefighting much more difficult and therefore most costly. Encouraging fire-safe practices through tax incentives would not be a new concept. Tax incentives are already used by both State and Federal Governments to promote energy conservation measures (e.g., insulation, thermal windows, weatherstripping), and they have been used in the past for other purposes. There is no reason, then, why such incentives should not be used by local and/or State governments to encourage fire-safe practices in or near wildland areas (e.g., fire engine access to swimming pool water, fire-resistant roofing, vegetative clearance, granting an easement for a fuelbreak). This approach would be accepted by property owners and occupants with much more grace than the regulatory approach (Alger 1971, Stallings 1970).

Proposed Standards: Enact through legislation tax incentives or penalties, or both, for compliance or noncompliance with minimum fire-safe practices as set forth in this report or as developed for local application based on actual experience and principles of fire behavior and meteorology and taking into account local natural vegetation.

UNDEVELOPED AREAS: AN ADDITIONAL PROBLEM

Millions of acres of forest, brush, range, and other wildland, both publicly and privately owned, are undeveloped, and probably will continue to be so. Public lands are most often set aside by law for watershed, recreation, timber production, range land, fish and wildlife, or some multiple-use combination. Only under very limited situations and under the terms of special use permits are structures allowed to be built on them. By public policy the vegetation is more valuable in these areas than residences or other structures would be. Private lands may be undeveloped for a variety of reasons: economic, physical, choice of lifestyle, legal access, etc.

In some ownerships, certain limited fire protection facilities can usually be found. Sometimes their real purpose is for land management (e.g., ranch roads for salting cattle or timber access roads). In other cases they were built specifically for fire protection (e.g., firebreaks and fuel breaks, helispots, water cisterns). Only rarely, however, and in very limited areas, have these facilities been adequate to protect nearby structures from the danger of conflagration (Los Angeles City-County Fire Bd. Inquiry 1971, Green 1977).

Two basic and several secondary reasons account for lack of fire protection in these areas. One is the sheer magnitude of the problem in reference both to area and to cost. California has between 9,000,000 and 20,000,000 acres of chaparral, and between 45,000,000 and 50,000,000 acres supporting other wildland vegetation. Many other States have similar vast areas of forest, brush, and range lands. Depending on type of vegetation, topography, and method used, the cost of treating an acre for fire hazard reduction ranges from $50 to $500 for initial treatment and from $5 to $50 per year for maintenance.[10]

The second reason for lack of fire protection is the increased hazard of these areas because of Federal and State policies of total fire exclusion, starting in the early 1900's. This policy has been modified only slightly to allow a limited amount of controlled burning for land management purposes. But fuel loadings—especially dead fuels—have built up to much higher levels than under primeval conditions. Thus fires continue to reach conflagration proportions regularly in spite of greatly improved firefighting capabilities, and the amount of treatment required to reduce the hazard to an acceptable level is considerably increased (Green 1977, Hanes 1974, Houts 1974, Montague 1974, Wilson 1974).

Certain legal constraints contribute to the problem of off-site fire hazards to the wildland residence. Some of these inhibit fire hazard reduction work generally, both on-site and off-site, while others pertain to the rights of adjoining property owners. Among the constraints that inhibit the work are liability laws and environmental protection statutes. The rights of adjoining owners affect the required clearances around structures located on small lots or those otherwise too close to the boundary (Los Angeles City-County Fire Bd. Inquiry 1971, Task Force on California's Wildland Fire Probl. 1972).

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[10] Task Force on California's Wildland Fire Probl. 1972, Green 1977, Hanes 1974, Houts 1974, Los Angeles City-County Fire Bd. Inquiry 1971, Montague 1974, Pacific Southwest Forest and Range Exp. Stn. 1963, Wilson 1974.

So far, fire hazard reduction and fuels management activities have been viewed by the courts as proprietary actions that benefit only the property owner—be it the government or a private owner. As such, any harm resulting to any other person (e.g., escaped fire, air pollution, drifting or translocated herbicides) imposes a liability, either civil or criminal or both, on the person or agency performing the act. Although entirely in keeping with the Anglo-American legal tradition, this interpretation completely ignores the public protection aspects of the activity. In the United States, most fire protection, other than that of some highly specialized industrial systems, is supported at public expense and is generally treated in the legal system as immune from liability in the absence of malice or gross negligence. Reduction of wildland conflagration hazards is an outstanding exception to this general rule (Task Force on California's Wildland Fire Probl. 1972).

The concept that fuels management activities are proprietary has inhibited such activities on private land in another way: All levels of government prohibit the expenditure of public funds for a private benefit. This is entirely proper, but it again ignores the public benefit to be derived, in addition to any private benefit, from the kind of activities in question. As a result a Federal, State or county fire department or forestry agency cannot assist a private property owner in other than a purely advisory capacity in fire hazard reduction except when a clear and present danger exists (Task Force on California's Wildland Fire Probl. 1972).

Environmental protection laws (e.g., air pollution control, water quality control, pesticide control) are for the most part narrowly single purpose in concept and execution. Such laws rarely recognize relative degrees of public hazard from sources other than those to which they directly pertain. Fire hazard in rural and wildland areas easily can be a much greater threat to public safety than temporary air pollution from a prescribed fire, the killing of a few ornamental plants by an aerially applied herbicide, or temporary water contamination, for example. However the conflicts of law involved are so serious as to make fire hazard reduction work extremely difficult to accomplish (Los Angeles City-County Fire Bd. Inquiry 1971).

The California Public Resources Code (Sect. 4291) requires the clearance of flammable vegetation for 30 feet on all sides of any structure, or to the property line, whichever is nearer. This law works reasonably well, assuming adequate personnel for enforcement are available, for the true rural residences at which it was originally directed (e.g., farms, ranches, mountain cabins). It is almost totally ineffective for the rural and mountain subdivisions which have become common in the past 10 years, at least until all the lots therein are developed with houses on them. As a consequence several cities and counties, most notably both the City and the County of Los Angeles, have enacted local ordinances extending the distance involved and imposing the requirement regardless of the property line. In most of the wildlands of the State or elsewhere throughout the country, however, the owner of a structure on a small lot or one which has been constructed less than 30 feet from the property line, cannot legally obtain fire protection clearance from the adjoining property owner (Task Force on California's Wildland Fire Probl. 1972).

Fuels Management

One solution to the threat posed by vast areas of vegetative fuels is to treat them so as to reduce the fire hazard they represent to an acceptable level. Reduction of the available fuel (dead and fine living) on broad areas or blocks is one method that can be used. Conversion of the vegetative type to a less hazardous type in long strips (fuelbreaks) strategically located in such a manner as to assist firefighters in controlling fires that do start is another. Such fuelbreaks (*fig.* 9) have proved effective in saving lives, property, and suppression costs. These two basic methods are not mutually exclusive and, with proper planning, can be combined for maximum protective effect.[11]

Hazard reduction on large areas would be prohibitively expensive. Its use is, therefore, limited to relatively small areas (seldom larger than a few hundred acres) in locations where the values to be protected are high (e.g., downslope or upwind from a small community). Fuelbreaks are also expensive, but their cost-benefit ratio over the millions of acres of concern is much more favorable, especially if they are planned, built, and maintained for multiple use (i.e., fire protection, recreation, livestock grazing, wildlife management, water yield) (Los Angeles City-County Fire Bd. Inquiry 1971, Orange County Bd. Sup. 1976, Green 1977, Stallings 1970).

Because of the expense and its purpose—to protect the public—most fuels management work is done by public agencies. When it is done on publicly owned land it generally requires only a budget justification insofar as the legislative body is concerned. For some agencies, for example, a parks department, however, a policy change may be needed. Fuelbreaks cannot always be located entirely on public land, but they lose most of their effectiveness if left open-ended. Therefore, in order for a system to be completed, or in some cases even begun (e.g., the Santa Monica Mountains in Southern California), the fuelbreak may often have to

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[11] Task Force on California's Wildland Fire Probl. 1972, Green 1977, Houts 1974, Lancaster 1974, Montague 1974, Orange County Bd. Sup. 1976, Pacific Southwest Forest and Range Exp. Stn. 1963, Stallings 1970.

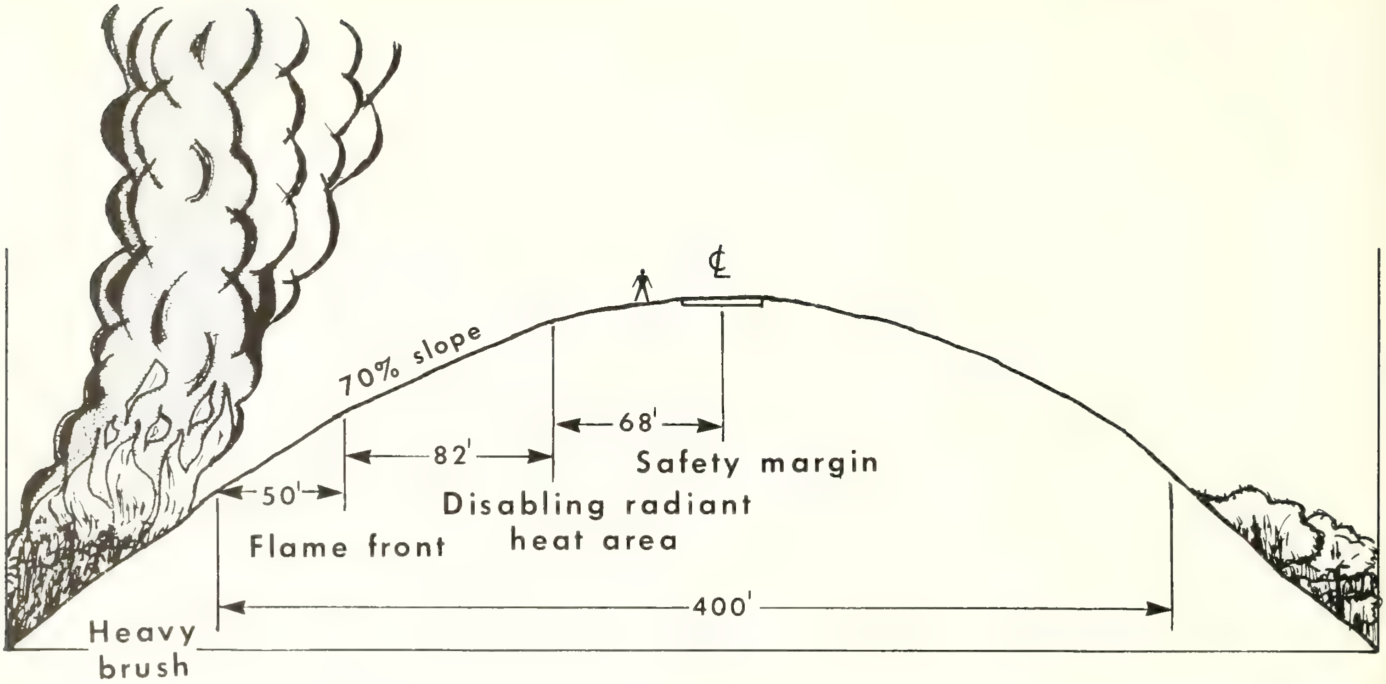

Figure 9—Distances recommended for personnel safety for the given terrain, fuel type, and conflagration burning conditions (Pacific Southwest Forest and Range Exp. Stn. 1963).

cross private land. An economic as well as a legal problem is created. This problem can be solved in any of several ways: (a) the public agency purchases the necessary strip of land (but purchase is seldom feasible unless the land is going to be used as a park or serve some other public function); (b) the agency acquires an easement or special use right-of-way at no or nominal cost, and the cost, if any, is paid either directly or by tax credit (Howard and others 1973, Stallings 1970).

The propriety of expending public funds for right-of-way access or for labor and materials to build and maintain fuelbreaks across private land is often questioned. Although the question can almost always be answered on the basis of an individual project, it would be much more logical to answer it once and for all by legislative policy. The same could be said for block hazard reduction or vegetative type conversion so long as a significant proportion of the benefits of the project could be shown to be for fire protection (Orange County Bd. Sup. 1976, Task Force on California's Wildland Fire Probl. 1972).

Proposed Standards: Build primary fuelbreaks (300 to 400 feet wide) on all main ridges, including motorways and helispots, and secondary fuelbreaks (minimum width of 200 feet) on key side ridges; evaluate the benefits to be gained from block treatment or type conversion of all critical areas upwind or downslope from communities, subdivisions, recreation sites, and other areas.

Legislation

Several matters concerning the fire safety of structures in wildlands as affected by off-site activities can be solved only by legislative actions at either the State or local levels. State Governments need to recognize the public interest in and benefit from fuelbreak, hazard reduction, and block type-conversion work whether done on public or private land. This recognition should then be related to the methods used and the legal implications of this kind of work. Where fire is used the term should be "prescribed fire" rather than "controlled burning." Fire hazard reduction should be given environmental protection status equal to air and water pollution and herbicide control. Where public benefits from work on private land are significant the State should share some of the costs; if not directly then indirectly by providing increased fire control standby services at public expense, for instance, co-insuring against any liability for escaped fire, or creating statutory limits on escape liability as long as certain standards of care were employed (Calif. Div. For. 1972, Lowden and Degenkolb 1972).

Vegetation clearance around structures is a special matter which probably requires legislative action at both State and local levels. California law requires such clearance for 30 feet and authorizes the State's Director of Forestry to require up to 100 feet if conditions are found to be extra hazardous. This statute has three weaknesses: (a) it cuts off at the property line if that is nearer than the 30 or 100 feet; (b) the Director's authority to delegate the determination of a need for a 100-foot clearance is unclear and has, therefore, never been exercised; and (c) no method or standards for determining "extra hazardous conditions" are provided (Task Force on California's Wildland Fire Probl. 1972, Lowden and Degenkolb 1972).

A very few local governing bodies have overcome the first defect in the State law by ordinance. These brush clearance ordinances operate in much the same manner as do the more common weed abatement ordinances for vacant lots. In effect, they declare brush or weeds on both the residence property and adjoining property to be a public nuisance because of fire hazard and require the abatement of the nuisance. Many more local jurisdictions could use similar ordinances profitably. The second and third defects could be quickly remedied by legislative action authorizing delegation and recognizing fire hazard severity classification as the standard (Los Angeles City-County Fire Bd. Inquiry 1971, Task Force on California's Wildland Fire Probl. 1972, Lowden and Degenkolb 1972).

Proposed Standards: Review laws, ordinances, regulations, and other measures related to wildland fire protection on the basis of recent scientific and technological knowledge, while discounting as much as possible emotionalism, fear, and legal precedent.

Fire Defense Systems

A total fire defense system includes all the manpower, equipment, real property and organization necessary to provide fire prevention and suppression for a given area or jurisdiction. The term is used here in the more limited sense of those improvements needed to enable firefighting forces to contain a wildland fire before it becomes a conflagration endangering houses and other structures. These improvements consist of fuelbreaks, fire roads (truck trails), helispots, safety islands, water cisterns, tractor trails, and similar items[3] (County Sup. Assoc. Calif. 1966, Lowden and Degenkolb 1972).

Such systems, to be effective, require detailed planning and large expenditures of manpower and money. Although not foolproof they have proved their worth on many occasions, and those concerned with the fire safety of homes located in or near the wildlands will find it worthwhile to push for construction and maintenance of these systems (Pacific Southwest For. and Range Exp. Stn. 1963, Task Force on California's Wildland Fire Probl. 1972, Green 1977, Lowden and Degenkolb 1972).

Proposed Standards: Ensure that fire defense systems are adequate to break broad expanses of vegetative fuels into manageable parcels, provide rapid and safe access for manpower and equipment for the quick suppression of fires, and provide facilities to replenish water supplies for fire trucks and helicopters.

Fire Alert Systems

A homeowner or other occupant can do much to help protect a home from wildfire. Most of the work should be done continuously or on a routine schedule, but unfortunately it usually is not. Whether done regularly or not it becomes of critical importance when the danger of a conflagration is imminent.

Under current practices of the Red Flag Fire Alert System, the public is usually not alerted until critical fire weather has arrived. Even then, there is no assurance that more than a small segment of the public is notified because agencies rely almost exclusively on commercial radio and television to broadcast information about critical fire weather. Weather forecasts published in newspapers and broadcast by radio and television seldom provide the public with enough advance warning to be of any significant benefit. Therefore, public notices made sooner—even if they proved to be false alarms and had to be cancelled, would probably be useful. Additional means of disseminating alert notices to the public need to be explored (Orange County Bd. Sup. 1976, Task Force on California's Wildland Fire Probl. 1972. Lowden and Degenkolb 1972).

Proposed Standards: Provide property owners in affected areas with positive notification of impending critical fire weather conditions at least 24 hours in advance of the arrival of such conditions.

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GLOSSARY

Chaparral: Native brush of mixed species (scrub oak, chamise, manzanita, toyon, etc. in California).

Conflagration: A large and destructive fire, usually aggravated by strong winds which carry firebrands over natural or manmade barriers.

Controlled burning: Fire used for land management purposes (e.g., range improvement) for which advance preparations are limited to installing control lines around the perimeter and sometimes crushing the vegetation to get a hotter fire. The only weather factor usually considered is wind of such force as to make fire control difficult.

Cycle time: The average time in years between vegetation fires in a given area. Usually applied only to fires of conflagration magnitude.

Dooryard: That area adjacent to a residence which is regularly used by the occupants and on which the native vegetation has been removed or modified, including driveways, parking areas, lawns, patios, play areas, etc.

Fuelbreak: An area, usually a long strip strategically located, wherein vegetative fuels are reduced in volume and maintained so as to produce a reduction of fire intensity if a wildfire burns into it.

Greenbelt: An irrigated, landscaped, and regularly maintained fuelbreak, usually put to some additional use (e.g., golf course, park, playground).

Mediterranean climate: A relatively mild weather pattern characterized by winter precipitation and long, hot, and dry summers.

Planned unit development: A real estate development, usually of large scale, which is planned and developed as a complete community, including residential, commercial, recreational, and school facilities as a minimum.

Prescribed fire: Fire used for land management purposes which is conducted under previously prescribed conditions of temperature, humidity, fuel moisture, and wind speed and direction to achieve a specific purpose, e.g., fire hazard reduction, site preparation for planting, control of certain unwanted plants, plant disease control.

Rural: Any area wherein the residences and other developments are scattered and intermingled with forest, range, or farm land and native vegetation or cultivated crops.

Urban: In this report refers to any area wherein the residences and other works of man form an essentially solid covering of the landscape, including most areas within cities and towns, subdivisions, commercial and industrial parks, and similar developments whether inside city limits or not.

Urban wildland interface: That line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels.

Wildfire: An uncontrolled fire, usually spreading through vegetative fuels but often consuming structures as well.

Wildland: An area in which development is essentially nonexistent, except for roads, railroads, powerlines, and similar transportation facilities. Structures, if any, are widely scattered and are primarily for recreation purposes. Includes large cattle ranches and forests managed for timber production.

The Forest Service of the U.S. Department of Agriculture

- ...Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.
- ...Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.
- ...Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

- ...Represents the research branch of the Forest Service in California, Hawaii, and the western Pacific.

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This guide, based on a literature review and personal contacts, offers recommendations and standards for procedures in reducing losses of residences from wildfires. Possible solutions to the problem of fire protection are discussed in the broad areas of land-use planning and zoning, property development, structural design and constrution, landscaping, accessories, occupant activities, and financial incentives. The problem of reducing fire losses in undeveloped areas is also discussed and solutions proposed. The guide is intended for homeowners, lawmakers, and members of the building, planning, and financial communities.

Retrieval Terms: fire prevention (structures), fire hazard reduction, water supply (residential), urban-wildland fire interface, insurance, construction materials (buildings)